# Electric Locomotives

Baldwin Locomotive Works
PHILADELPHIA,
AND

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O. B. Mitcham.
Captain of Ordnance.

Received
September 22nd,
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# ELECTRIC LOCOMOTIVES

BALDWIN LOCOMOTIVE WORKS

BURNHAM, WILLIAMS & CO.

PHILADELPHIA, PA., U.S.A.

AND THE

WESTINGHOUSE ELECTRIC AND MFG. CO.

PITTSBURG, PA., U.S.A.

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PHILADELPHIA

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ELECTRIC locomotives are adapted to a variety of conditions. For suburban and elevated railroad work their advantages are acknowledged. The cost of operation, including labor and repairs, is low. The machinery is mainly below the floor of the cab, therefore practically the entire floor space is available for freight or passengers. On heavy grades, such as are often found on suburban roads in a rolling country, the electric locomotive can haul more paying load than a steam locomotive of the same power, as all weight in locomotive not required to secure traction is removed. A less expert class of help can generally be used for operation and repairs. In most cases one motorman is sufficient for an electric locomotive, while on a steam locomotive a competent engineer and fireman are necessary.

For hauling in mines the electric locomotive is superseding steam and mule power. In well ventilated mines there is no danger from the ignition of the gas by sparks from the electric machinery, and the electric locomotive does not vitiate the air. The small amount of apparatus necessary for the installation of the electric plant is in its favor, as a small copper wire takes the place of the large amount of piping and the air storage tanks for pneumatic locomotives. The weight of an

electric locomotive is less than that of a compressed air or steam locomotive adapted to the same work, as the apparatus for generating or storing the power is in a central station instead of on the machine, as is the case with steam and pneumatic locomotives. The capacity for hauling on grades is greater, as the full power of the central station is available, up to the full capacity of the motors, which are thus able to perform temporarily an abnormal amount of work instantly when called upon for such service.

For switching in yards and about manufactories, especially where electric power is employed for other purposes, the electric locomotive presents important advantages, as it is easily repaired, simple to operate, and inexpensive to maintain. When the electric locomotive is not in use the deterioration is small, as there are practically no parts to become weakened by rusting, as in the case of steam and pneumatic locomotives. Where the demand for the service of a locomotive is intermittent, the electric type has an important advantage, as no power is used when the locomotive is idle.

The electric locomotives and trucks shown and described in this volume have been designed to meet the increasing demand for equipment for electric railroads. The end that has been kept in view is the selection of types of construction which will give the best efficiency with the least first cost.

The details of construction have been arranged in the same careful manner as for steam locomotives, and it is intended that the workmanship and material shall be the best. The apparatus illustrated is designed for use with direct current.

The Tesla locomotives for the alternating current do not differ materially in appearance, but only in the details of the electrical apparatus.

The standard trucks have been devised to resist for long periods of time the severe twisting strains which arise from the torque of electric motors. To accomplish this, the transoms and sides are strongly braced, and the parts are fitted together with planed surfaces and turned taper bolts.

The mine locomotives have been made more compact than heretofore, so that, although parallel rods are used, the width is less. The details are simple in form and accessible for repairs. These mine locomotives receive the same care in workmanship and material as steam locomotives.

A Glossary of Terms, giving simple definitions, some explanation of the elementary features of electric motors, and a few useful tables and diagrams have been added.

**BALDWIN LOCOMOTIVE WORKS,**
**BURNHAM, WILLIAMS & CO.**

**WESTINGHOUSE ELECTRIC & MFG. CO.**

**Philadelphia, Pa.**
**Pittsburg, Pa.** } **March, 1896.**

# CONTENTS.

# Classification.

THE following classification is adopted for electric locomotives:

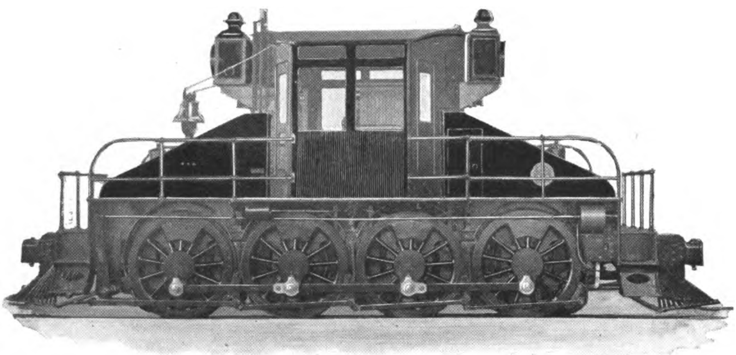
An initial figure, 4, 6, 8, etc., represents the total number of wheels under the locomotive. The size and number of motors are designated by a fraction, the numerator of which represents the number of motors used, and the denominator the horse-power of each motor. A final letter, C, D, E, etc., indicates the number of pairs of wheels which are driven directly by the motors; thus, $8\text{-}\frac{2}{100}$ C represents a locomotive having eight wheels, with two 100-horse-power motors, and two pairs of driven wheels, with or without connecting-rods. C indicates two pairs, D three pairs, and E four pairs of driven wheels.

# Connections between Armature Shafts and Driving-Axles.

An important advantage of electric locomotives is that all axles can be driven. In this way the entire weight of the locomotive and its load can be utilized for tractive power, and the weight on driving-wheels is not limited to a fraction of the total weight, as in steam locomotives. The weight of the necessary electrical and mechanical parts to produce an electric locomotive of a given power is not usually sufficient to give the desired tractive power,—hence, most electric locomotives have to be increased in weight. This is done either by the freight which the locomotives can carry or by adding permanent weight, usually cast iron, to the structure. There is a wide difference in the weights of electric locomotives of the same

power. This difference arises mainly from variations in the designs of the connections between the armature shafts and the driving-axles. If the armature shaft revolves no faster than the driving-axle, the motor will be heavy in proportion to the work it can do, except in cases where the speed is exceedingly high, say from seventy to one hundred miles an hour. For all common speeds the weight of the motors is excessive when the connection between the armature shaft and the axle is such as to compel both to travel at the same number of revolutions per minute. The type of motors known as the "gearless," or "direct-connected," belong to the class in which the armature speed and the axle speed are the same. The power is transmitted either by a parallel rod from a crank on the motor shaft to a crank on the axle, or the armature is made concentric with the axle,—that is, the axle is practically the armature shaft. An example of the gearless locomotive is given by Fig. 1.

Fig. 1.



**Gearless Electric Locomotive, 1000 H.-P. Type, Side View.**

When the armature is concentric with the axle, it is sometimes fixed rigidly thereon, or is placed on a hollow spool or sleeve which surrounds the axle and drives it by means of a clutch or drag link.

The parallel rod connection is perhaps the least objectionable, from the fact that its construction permits the motors to be carried on springs, thus relieving the axle of a large amount of

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Comd'g Detachment.



dead weight. Where the armature is rigid on the axle, it is necessary to support the heavy field castings also thereon. This places the entire dead weight of the motor on the axle. In the sleeve construction, either with drag link or clutch, there is a slight motion between the sleeve and the axle vertically, but this motion is small, and the load on the axle is comparatively rigid.

The objections to the gearless motor are less in theory than in practice. For street-car work they have proven so inefficient that they have been abandoned. Among the practical objections are the following: *First.* It is undesirable to have more dead weight than is necessary on an axle, owing to the damage to the rail by the shocks produced by rigid masses going over the joints. *Second.* The shocks from rigid weight are detrimental to the axle, and the jarring of the motor, armature, and commutators with a rigid construction causes deterioration of the insulation and rapid wearing of the bearings. The shocks cause loose parts to chafe and cut through the insulation. *Third.* The sleeve construction is complicated and expensive, as the sleeves must be made of the best quality of forged steel. The bearings of the sleeves in the field magnets are difficult to keep cool. The oil from the driving-boxes of the locomotive is thrown on the motors, and is liable to damage the insulation. In this form of construction, as well as where the armatures are rigid, the repairs to wheels, axles, and motors are difficult to make, and it is impossible to remove the axles or wheels from the locomotive without removing the motors also. To re-wind the armatures or fields often requires the removal of the axles from the driving-wheels by hydraulic pressure.

With a geared motor the speeds of the armatures and axles are independent. The ratio of the gearing regulates the relative speed, and the gearing can be changed so that an express locomotive for high speed can be made suitable for freight work by simply changing gears, without any other change in the machine. It may be necessary in some instances, in order to get a sufficiently powerful motor on narrow gauge locomotives, to use an intermediate gear, and in rack locomotive motors,

and others which travel at a very low speed, it may be advisable to use a double-reduction gear.

With a direct-connected machine, each motor must be wound for the work it has to do; and where there are many locomotives, the complications arising from the non-duplication of details is objectionable.

The wear on the gears is small; and, as they are made in halves, they are easily replaced without removing the wheels or motors from under the locomotive. The axles and motors being independent, one can be removed without disturbing the other.

The modern form of gear transmission between electric motors and axles is the most efficient of any driving mechanism known, and the loss of power where gears are run in oil in gear cases, is not more than three per cent., and it is generally less. The noise and wear, which were the original objections to the use of gears, have, by improved tools and materials, been so reduced as to be unobjectionable. The weight of the geared motors is so much less as to reduce materially the cost of electric locomotives, while the efficiency is increased, so that for all ordinary speeds the geared motor is the most efficient, the lightest, cheapest, and most durable type, as well as the simplest in construction, and the easiest to maintain. Based on practical experience, it may be said in round figures that direct-connected electric locomotives cost about three times as much as geared. They are less efficient and more complicated.

# Express Locomotives.

These locomotives are made for any horse-power from 100 to 1600, and of the type shown by the illustrations, Figs. 2 and 3. They are made up of two substantial four- or six-wheel trucks, equipped with motors and surmounted by a heavy channel-iron frame, devised to take the severest shocks to which locomotives are subjected in regular service.

To increase the stiffness, the frame is covered with a one-half inch steel plate on top throughout its entire length. If necessary to give additional weight for adhesion, cast-iron plates may be added to the floor.

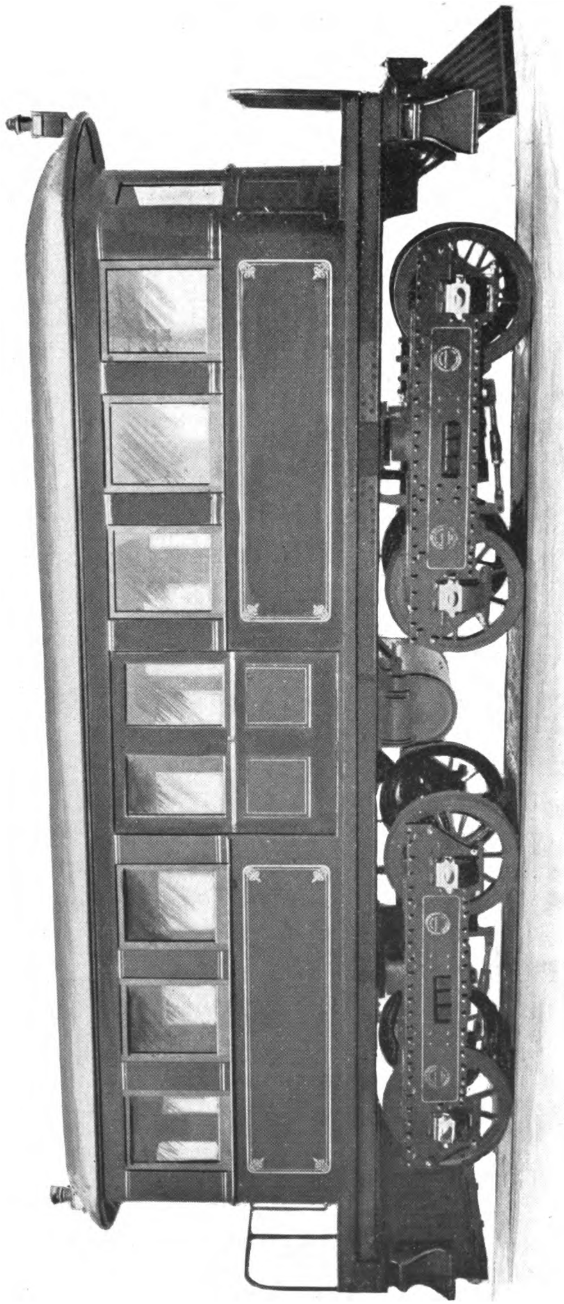
The interior of the cab is open, and available for freight or baggage, except at one end, where a small space is taken up by the single controller. This controller is operated from both ends of the locomotive.

Double sliding-doors are provided on both sides, to facilitate handling baggage or freight. There are end-doors to give access from the train.

These locomotives are adapted to run at any desired speed. When the weight is known, the hauling power can be determined from the diagrams of draw-bar pull and torque.

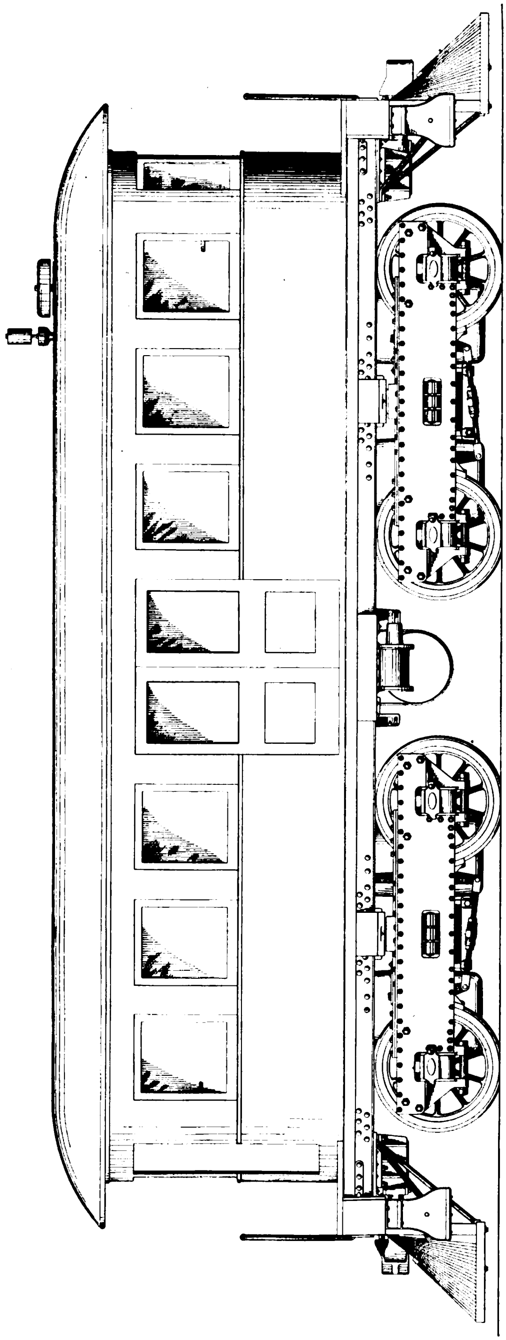
For high speeds, protection is provided for the engineer to prevent, as far as possible, accidents arising from the breaking of the windows by objects thrown from the track by the pilots.

Fig. 2.



Eight-Wheel Express Locomotive, Class 8-$\frac{4}{200}$ E.
(Without Motors.)

Fig. 3.



**Eight-Wheel Express Locomotive, Class 8-$\frac{4}{200}$ E.**

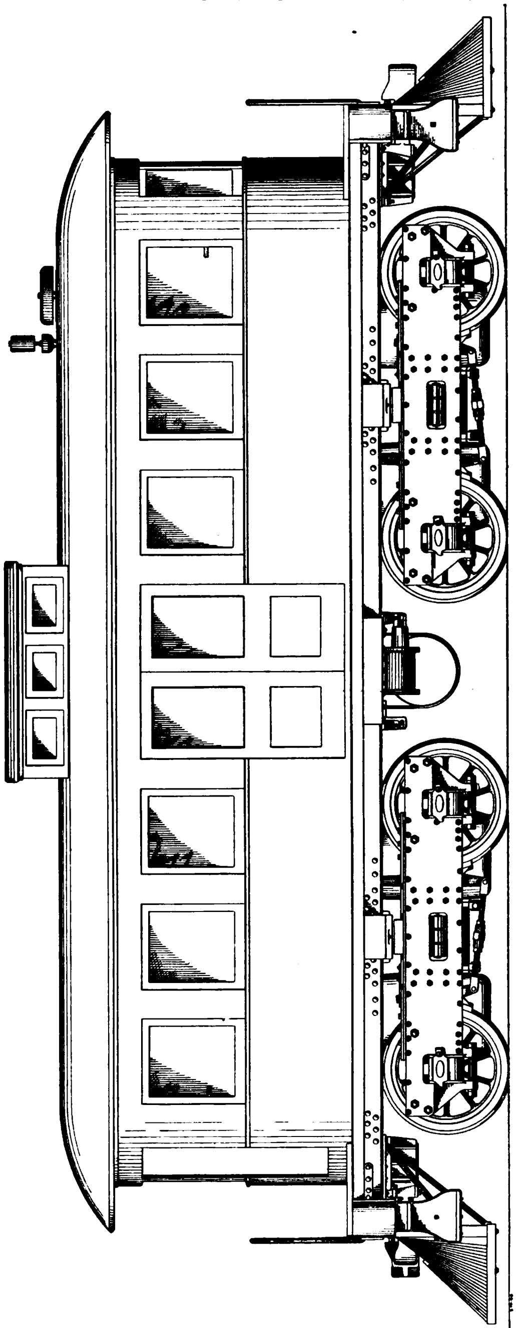
# Freight Locomotives.

The freight locomotives are made for any horse-power from 100 to 2000, of the type shown by the illustration, Fig. 4. The locomotive is made up of two substantial four- or six-wheel trucks equipped with motors, and surmounted by a heavy channel-iron frame devised to take the shocks received in switching.

If the freight to be carried by these locomotives is not sufficient to give the desired adhesion, permanent weight can be added to the floor for this purpose. The interior of the cab is open and available for freight, except at one end, where a small space is taken up by the single controller. This controller is operated from both ends of the locomotive. Double sliding-doors are provided on the sides, to facilitate the handling of such freight as may be carried. There are doors at each end, to give access to the locomotive from the train.

Double locomotives are formed of two short freight locomotives coupled at the centre. All the motors are controlled by one controller placed in the cab. When the conditions are favorable, electric locomotives for this service are made with six or eight wheels contained in one rigid frame and coupled with parallel rods.

Fig. 4.



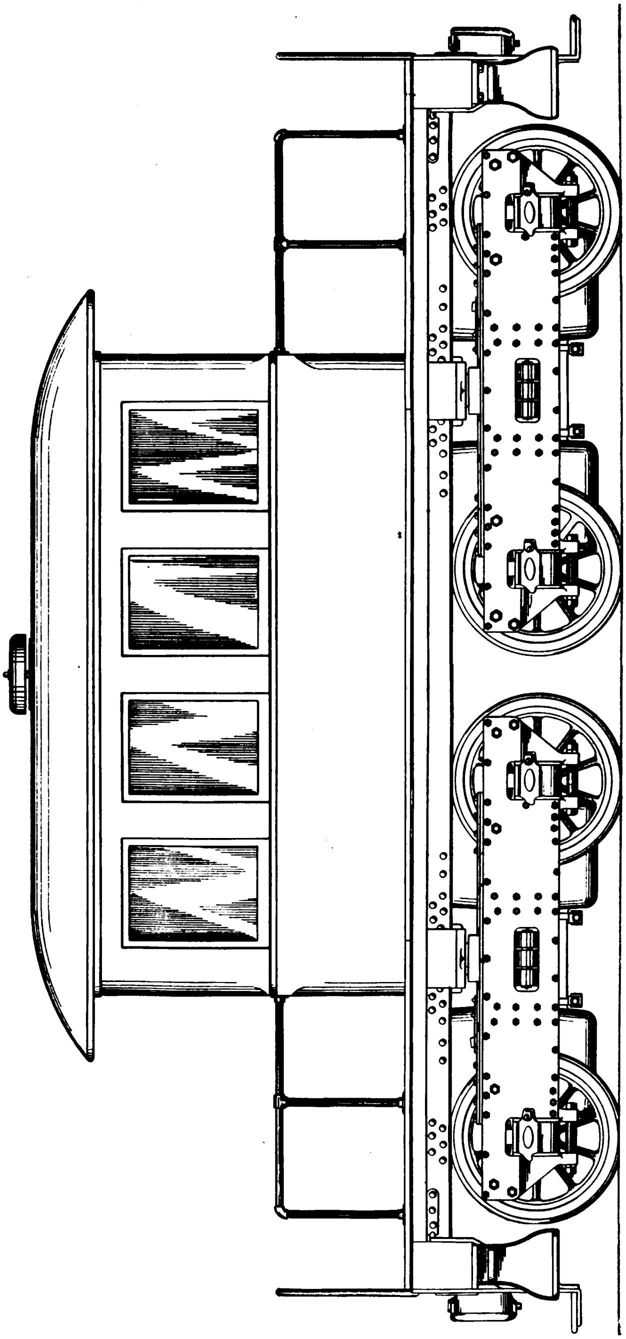
**Eight-Wheel Freight Locomotive, Class 8-$\frac{4}{200}$ E.**

## Switching Locomotives.

The larger switching locomotives have the same fundamental features as the freight locomotive; viz.: two trucks, one under each end, each truck being fitted with two motors, with a capacity varying from 50 to 200 horse-power each. These trucks are placed under a strong channel-iron frame, the length of which is made as short as possible, but in all cases permitting the trucks to clear each other on curves. The four-wheel switchers have the motors and axles fixed in a frame, rigid with the cab.

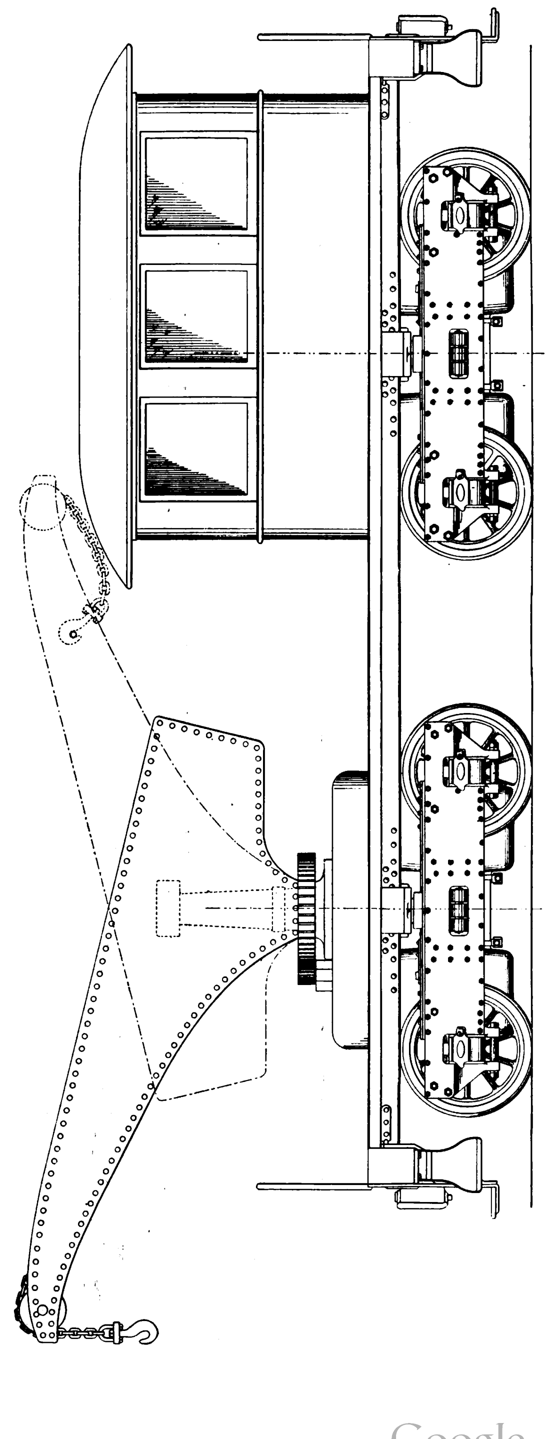
The superstructure, or cab, is made long or short, according to circumstances. Usually the cab is short, and placed in the centre of the locomotive, allowing a large space on each end, on which freight can be carried. These locomotives, when desired, have a crane at one end and a cab at the other. This crane is driven by an electric motor, and may have any required capacity. Switchers of this kind make excellent wrecking cars, and can be used in unloading freight. Figs. 5, 6, and 7 illustrate some of the different types of switching locomotives.

Fig. 5.



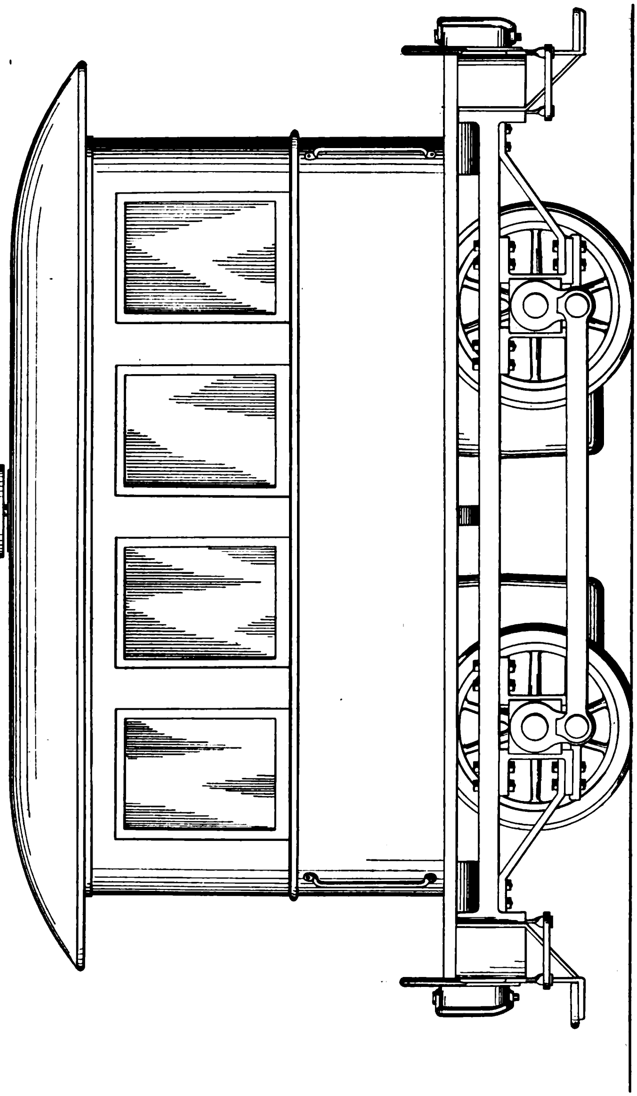
**Eight-Wheel Switcher, Class 8-$\frac{4}{200}$ E.**

Fig. 6.



Eight-Wheel Switcher, with Electric Crane, Class 8-$\frac{4}{200}$ E.

Fig. 7.



**Four-Wheel Switcher, Class 4-$\frac{2}{100}$ C.**

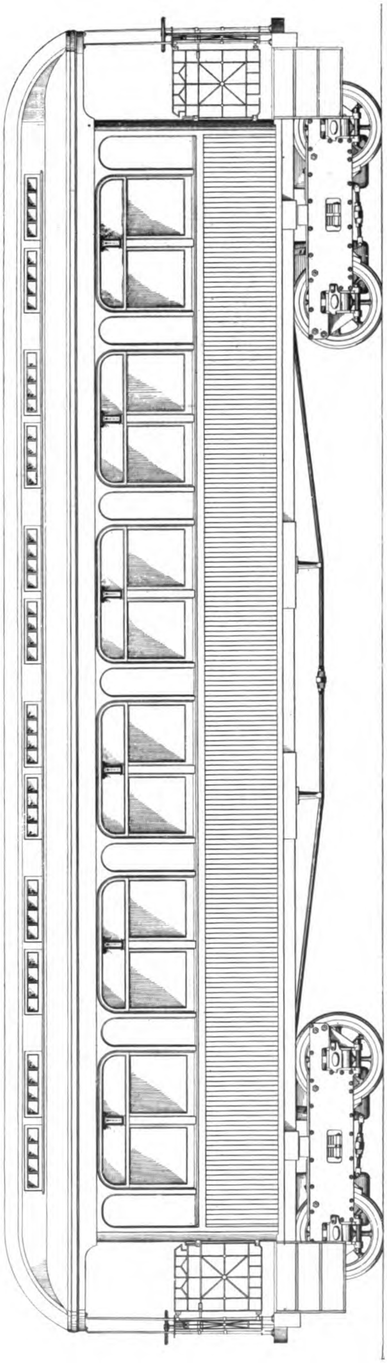
# Suburban and Elevated Railroad Locomotives.

The illustrations, Figs. 8 and 8A, show a type of suburban and elevated railroad locomotives. It has two four-wheel trucks, with two motors on each truck, varying in size from 50 to 200 horse-power, as may be required. One type of truck is shown by Figs. 13, 14 and 15. The underframe of the locomotive is made of channel-iron and is covered with a ⅜-inch plate of steel from end to end, which maintains the frame in rectangular form and adds to its strength to resist collisions. The superstructure is made according to the wishes of the purchaser, and seats are provided in the interior as may be desired. The entire floor is available for seating capacity, except at one end, where a small space is provided for the controller and rheostats. These locomotives can be operated from either end; and the space for the motorman on the end opposite the controller, when not in use, is available for seating passengers. The air-pump is placed under the locomotive or in the interior, as desired.

Owing to the simplicity of the controlling apparatus and the compactness of design, there are but two main conductors passed through the flooring; one goes to each truck. The conductors between the controller and the resistance box are very short, as these parts are arranged together in compact form.

Each locomotive is provided with an ammeter, a volt meter, and an engineer's brake valves, at each end. Each motor circuit

Fig. 8.

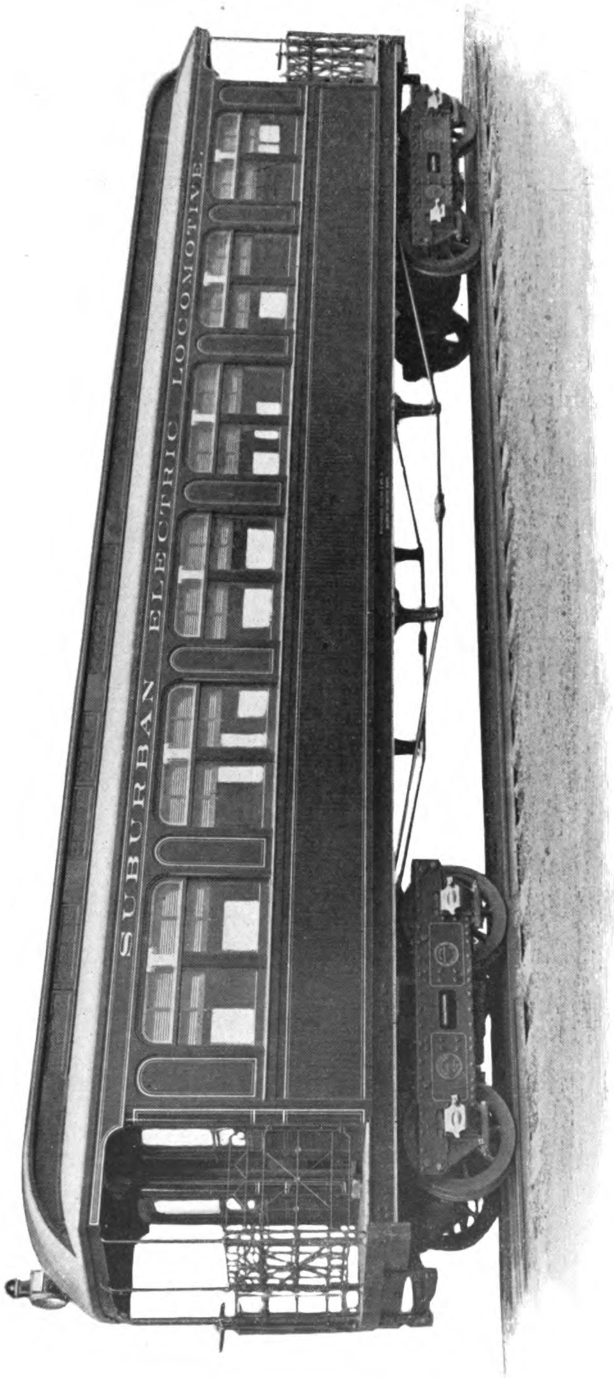


**Motor Car for Elevated and Suburban Railroads, Class 8-$\frac{4}{100}$ E.**

has an automatic circuit breaker, which will automatically cut out the current in case anything happens to the motor, or when it is overcrowded. In the main circuit there is a large circuit-breaker adapted to be opened whenever desired by the engineer, and always opened by air pressure whenever the handle of the engineer's valve is placed in the emergency position. All switches and instruments are mounted on a switch-board made of vulcanized fibre.

These locomotives are provided with platform railing and gate, and arranged to receive passengers on both sides of both ends. The arrangement is one that gives free ingress and egress, and permits the use of almost the entire floor space for passengers.

**Fig. 8A.**




**Motor Car for Elevated and Suburban Railroads, Class 8-$\frac{4}{100}$ E.**

# Mine Locomotives.

The capacity ranges from 50 to 200 horse-power, and the draw-bar pull from 3,000 to 10,000 pounds or more, according to the weight. The draw-bar pull may be increased by adding cast iron to get adhesion.

The locomotives are constructed with wrought iron forged frames, made in the same substantial manner as for steam locomotives. For the slowest speeds these locomotives have double reduction gearing. The gears are of cast steel or malleable iron, machine cut, and run in oil-tight cases.

The motors are hinged to the axle on one side and are supported on springs on the other side, thus providing a flexible support.

The smaller sizes may be adapted for wooden rails. Where the wooden rails have not an iron edge, the wheels are made with a special tread and flange, and therefore a description of the rail on which a locomotive is to run should always accompany an inquiry.

The normal maximum speed is ten miles an hour; but, by changing the gearing between the armature and the axles, the speed may be increased to twenty-five miles an hour or more.

The construction is simple. The motors are so hung that they are free to rise and fall with the irregularity of the track and are flexibly supported.

The frames rest upon springs, which in turn bear upon the axle boxes. All shocks in coupling are transmitted from end to end of the locomotive through heavy castings, and the pull is taken by the frames or by large links or rods connecting the foot plates.

All these locomotives have parallel rods, which prevent loss of power and time, due to slipping of individual axles. This is an important feature where there is fine coal-dust or moisture.

Each locomotive has two sand-boxes front and back, all of which can be operated from either end. These sand boxes can be provided with electric heaters, if desired, to keep the sand dry. The protection for the head of the motorman is hinged to swing so that the motorman can stand erect in parts of mines where the head room is sufficient.

Suitable brakes are provided, which can be operated from either end, and powerful enough to utilize the entire adhesion for braking force.

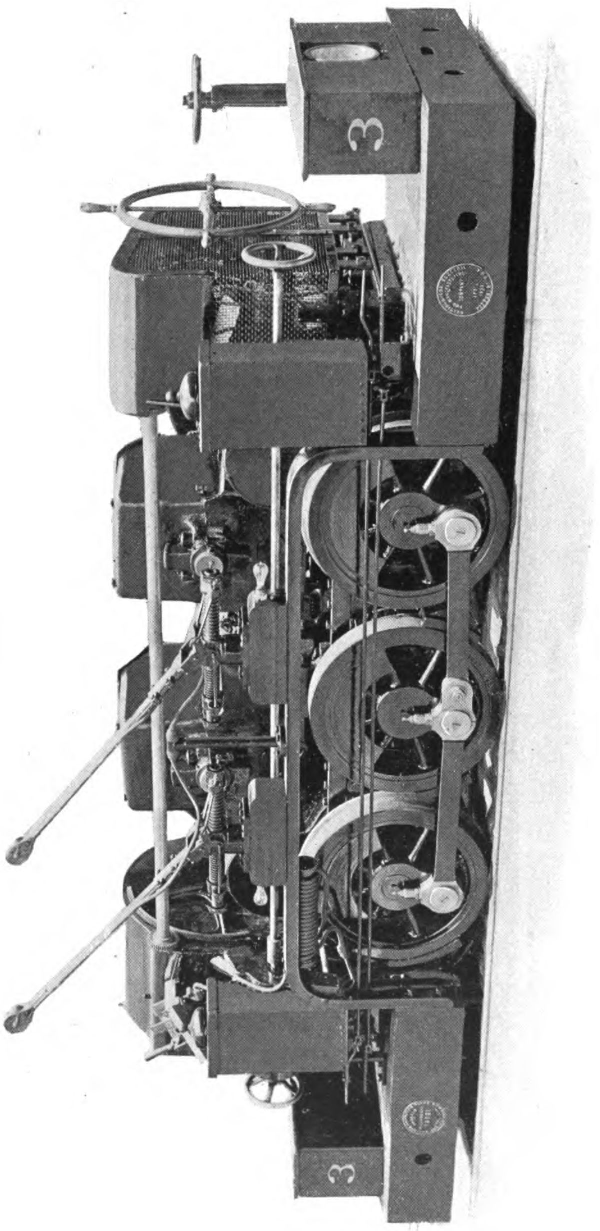
The electric motors have cast-steel fields and armatures with good ventilation ; they are iron-clad and not affected by moisture or rain more than the motors used on street cars. They are so protected in the locomotive as not to be liable to injury by shocks or by falling rock.

The gears are of the best wearing material, accurately cut. The wheels may have chilled treads or steel tires shrunk on. The crank-pins and parallel rods are of open-hearth steel. The rods have hard bronze bushings.

All accessories are furnished, including switches, cut-outs, trolley poles, diverters, controllers, etc., necessary to make the locomotives complete in every detail, ready for operation.

All parts are made by templates and gauges, so as to be interchangeable in every respect. All important bolts are turned taper and are made of driving fit. In construction, the same accuracy of workmanship is given to electric mine locomotives as to steam locomotives.

Fig. 9.



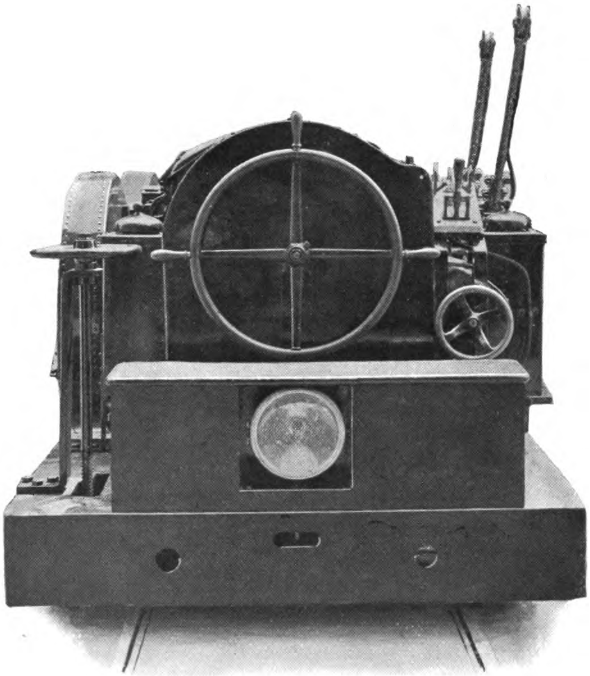
**Six-Wheel Mine Locomotive, 200 H.-P., for Narrow Gauge.**

One of the largest of this class of locomotive is shown by Figs. 9 and 10. It has a capacity of 200 H.-P. at six miles per hour with a track gauge of three feet eight inches. These requirements make it necessary to raise the motors above the wheels, and to use intermediate gearing. The illustrations, taken from a photograph of the uncovered machine, show how this is accomplished.

When so specified, mine locomotives may be provided with a metal shield or cover, which is in some cases a desirable protection. Covers of this sort are not needed except for special conditions, and not advisable for common practice, as they restrict the ventilation of the armatures, and retard the cooling of the motors and rheostats. For the larger sizes of locomotives, they are heavy, and prevent quick access to the machinery for running repairs. It is desirable with electric locomotives, as with steam locomotives, that all wearing and moving parts be under the eye of the engineer when the machinery is in operation.

The 200 H.-P. mine locomotive shown in the illustrations is covered only at the points requiring protection from rain, hence all parts are accessible and can be watched by the engineer while in motion.

Fig. 10.



**Six-Wheel Mine Locomotive, 200 H.-P., for Narrow Gauge.**

# Rack Locomotives.

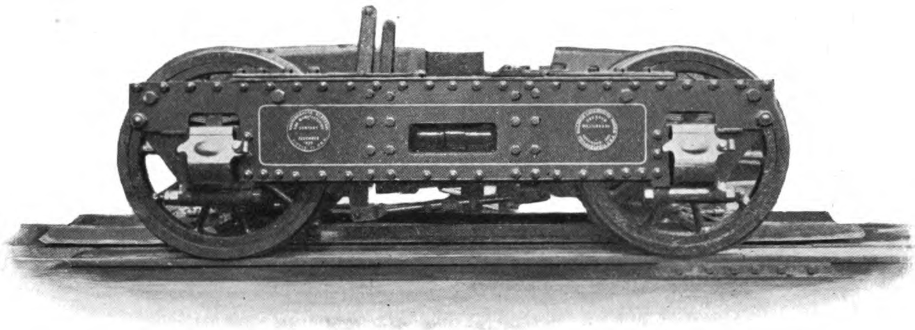
Rack locomotives are made for any system of rack and gears, and are adapted to operate upon any practicable incline. One point of advantage with electric rack locomotives is that the weight of the locomotive is only that necessary to keep the gear wheels in the rack. Such locomotives do not carry boilers and engines, as is the case with steam locomotives, therefore with an equal rated power the electric locomotive can haul a greater load.

# Trucks.

The axles of the ordinary car truck are not driven, but the truck is hauled by a locomotive. Electric locomotive trucks have driving-wheels, and therefore must be adapted to pull cars. This throws quite a different stress on the transoms and necessitates a much stronger and more rigid construction. In order that the motors may be reversible and interchangeable, they must drive the axles at opposite sides of the truck ; this produces a distorting stress tending to put the frame "out of square."

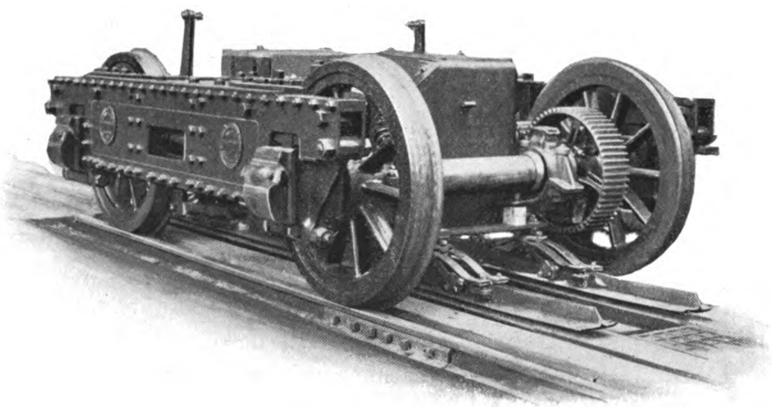
Figs. 11 to 15 represent a truck designed especially for use under an electric locomotive. The transoms of the truck are provided with a substantial gusset to the side frame, and knees and brackets are introduced to hold the frame perfectly square and true, and enable it to withstand the distorting stress developed in the truck by the operation of the motors. Care is taken that the boxes and journals shall be of the proper form and size to give adequate wearing surfaces, and that they shall be so fitted as to resist properly the shocks transmitted to them without being thrown out of line. The weight of the trucks and motors is supported on the journal boxes by means of suitable springs with limited range of motion. A swing bolster of improved design is introduced to carry the weight of the car ;

Fig. 11.



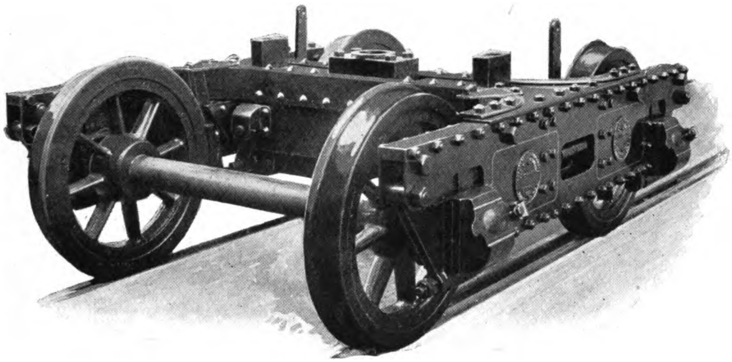
Truck for Electric Locomotives, Class 8-$\frac{4}{200}$ E.

Fig. 12.



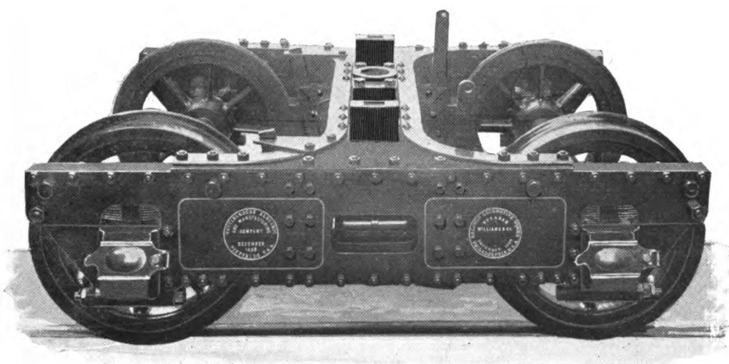
Truck for Electric Locomotives, Class 8-$\frac{4}{200}$ E, End View, with Gear Case removed to show Gearing.

Fig. 13.



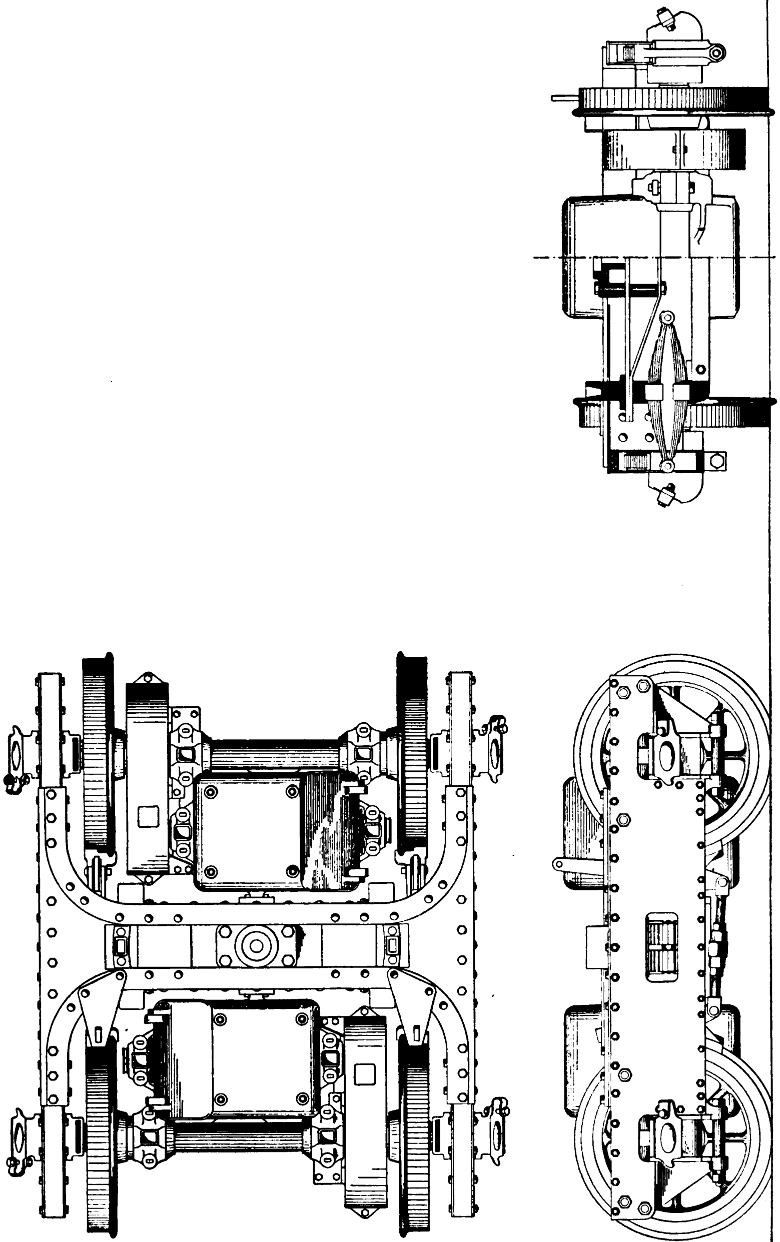
**Truck for Motor Cars for Suburban Railroads, Class 8-$\frac{4}{100}$ E.**

Fig. 14.



**Truck for Motor Cars for Suburban Railroads, Class 8-$\frac{4}{100}$ E.**

Fig. 15.



Truck for Motor Cars for Suburban Railroads, Class 8-$\frac{4}{100}$ E, showing Motors in Position.

this is connected to the truck by suitable links, and provided with easy-riding double-elliptic springs.

For the purpose of gaining access to the parts of the truck, and for readily removing the wheels, axles, and boxes, a swinging jaw may be arranged to form the outer pedestal leg. This is secured to the truck frame by a joint connection, and securely held in place by the pedestal-cap bolt. When desired, it can be lifted, and the released parts removed without taking the truck from under the car. The swing bolster and springs can be dropped down and taken out without disturbing any of the other details of the truck. The brakes are arranged without brake-beams, so as not to interfere with the removal of the swing bolsters or motors. The motor hangers are so placed that the motors can be dropped out of the trucks without taking down the swing bolsters or the brakes, and without removing the wheels or axles.

The workmanship in these trucks is equal to that in steam locomotive construction. All the bolts are turned taper to a driving fit in reamed holes, and all parts are well fitted with planed surfaces.

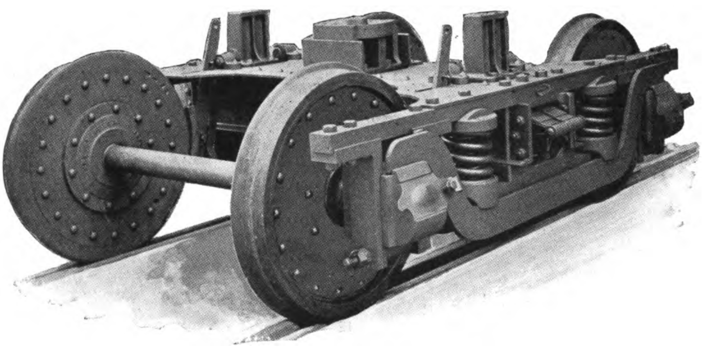
A parallel rod can be provided at small additional cost, if desired, as the strength of the design has been made with this in view. Where it is not desirable to use sand, and where the motors are to be started with full power, it is often best to use parallel rods.

Figs. 11 and 12 show the truck for the Class $8\text{-}\frac{4}{200}$ E locomotive. It is adapted for use with either the 200 or 100 horse-power motors. The wheels may be made forty-eight inches in diameter without increasing the wheel-base above seven feet six inches.

Figs. 13 and 14 show the truck for the Class $8\text{-}\frac{4}{100}$ E locomotive. It is adapted for use with either the 50 or 100 horse-power motors. The wheels may be made thirty-six inches in diameter without increasing the wheel-base above six feet. Fig. 15 shows the 100 horse-power motors in position on this truck. This truck is also made with a short pedestal to clear the guard-rail bolts on elevated railroads.

Fig. 16 shows an open frame truck with swing bolster of the size suitable for the 100 horse-power motor. All the joints are planed and the bolts are turned taper and driven in reamed holes. The brasses are machine-fitted in the boxes. This truck has the same type of spring arrangement as is commonly used under passenger coaches, and rides as well as the best forms of four-wheel trucks.

**Fig. 16.**



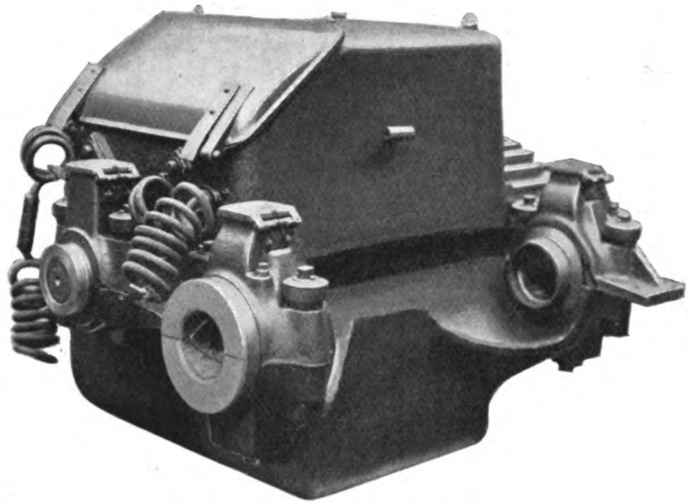
**Electric Locomotive Truck, with Open Side Frame and Swing Bolsters.**

# Motors.

Unless otherwise specified, "iron-clad" consequent-pole motors are used. The external appearance of these motors is shown by Figs. 17 and 18. Fig. 17 shows the motor with the cables leading to it, as it appears from the side where the axle brackets are placed. Fig. 18 shows the motor on the opposite side, where it is supported on the truck frame. A section through one of these motors is shown by Fig. 19. One of the field coils is shown in Fig. 20. The armature with the pinion gear is given in Fig. 21, and the lower field magnet without the armature in Fig. 22. Fig. 23 shows the lower field with the armature, looking from the side next the axle. Other views of these motors, showing the armature in position in the lower field magnets, are given by Figs. 24 and 25, and Figs. 26 and 27 give views of the completed motor from both sides. These motors are entirely encased by thin steel shell, so that they are practically free from injury under all normal conditions of service.

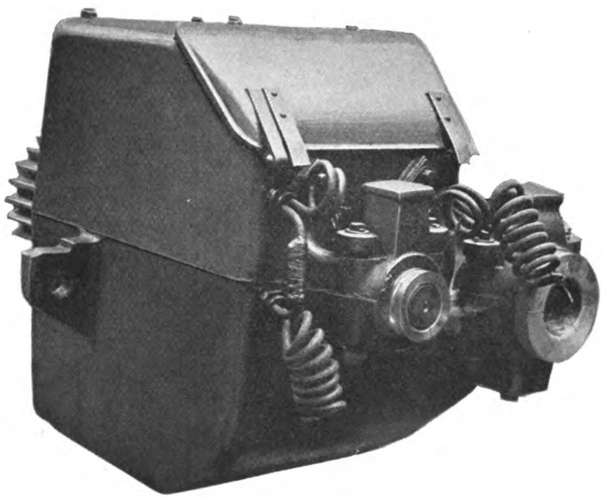
The armatures are laminated, and are made up of thin slotted discs of steel, as shown in Fig. 28. In the slots are placed the armature wires, Fig. 29. The commutators are of the best forged copper, with mica insulation. A segment of the commutator is illustrated by Fig. 30. These motors are of modern construction, with ventilated armatures, steel fields, and the highest grade of insulation. Only the most perfect material is used, and all machines are tested to their full capacity before shipment.

Fig. 17.



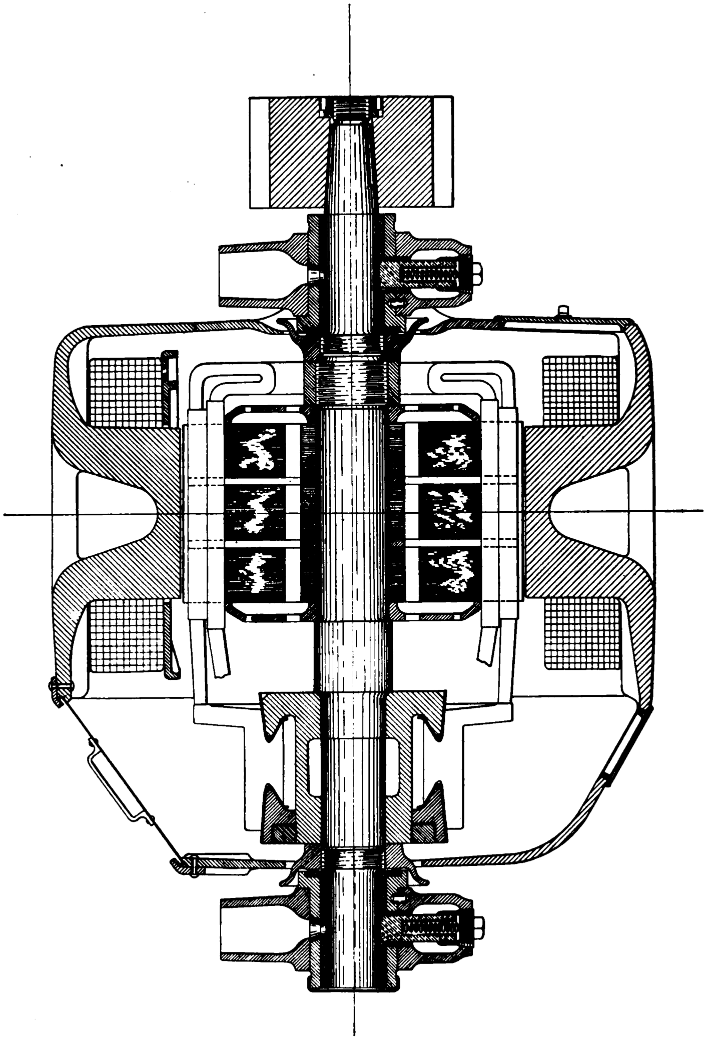
Consequent Pole Railway Motor, showing Axle Brackets.

Fig. 18.



Consequent Pole Railway Motor, showing Armature Bearing on Commutator End.

Fig. 19.

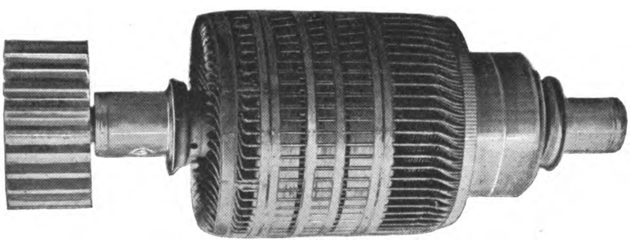


Section of Electric Motor, Consequent Pole Type.

Fig. 20.

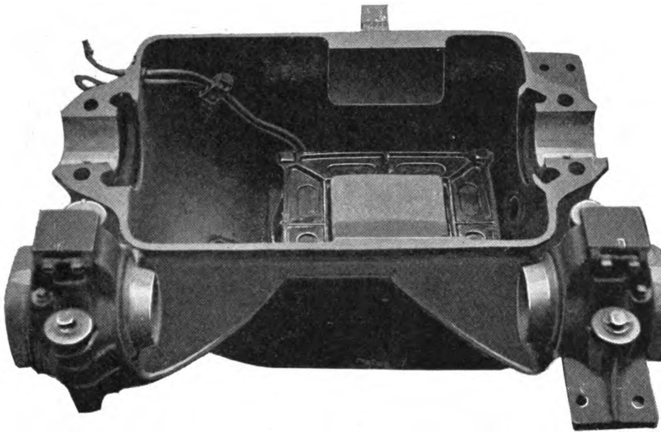
Consequent Pole Railway Motor Field Coil, showing Wire Connections.

Fig. 21.



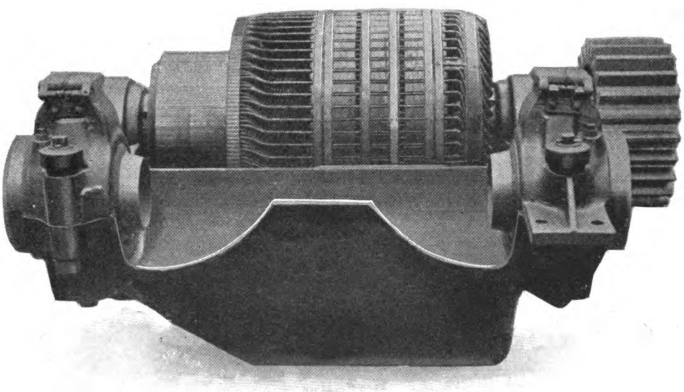
Armature, showing Winding and Pinion.

Fig. 22.



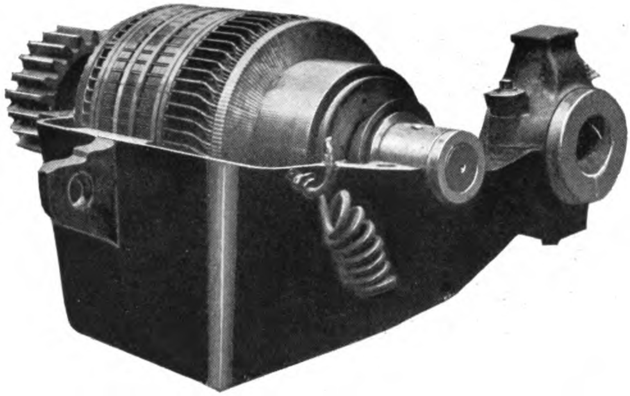
**Lower Field Magnet, showing Field Coil in Position.**

Fig. 23.



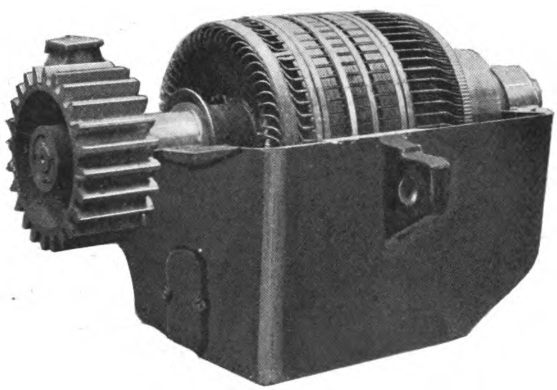
**Motor with Top Field Removed, showing Axle Brackets and Armature in Position.**

Fig. 24.



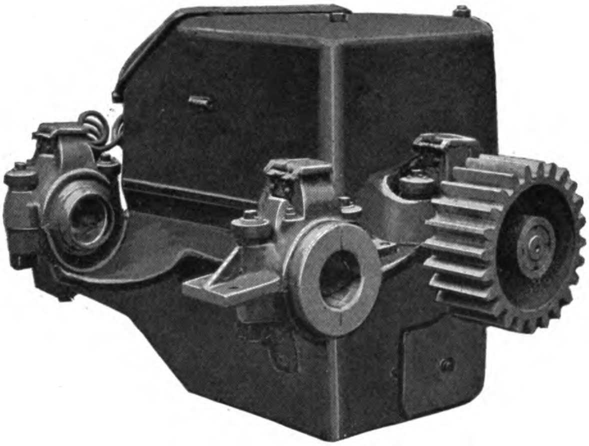
**Motor with Upper Field Removed, with Armature in Position, showing Wire Connections.**

Fig. 25.



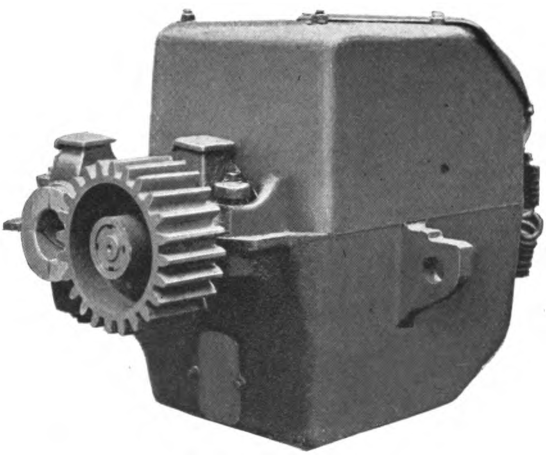
**Motor with Upper Field Removed, with Armature in Position, showing Pinion.**

**Fig. 26.**



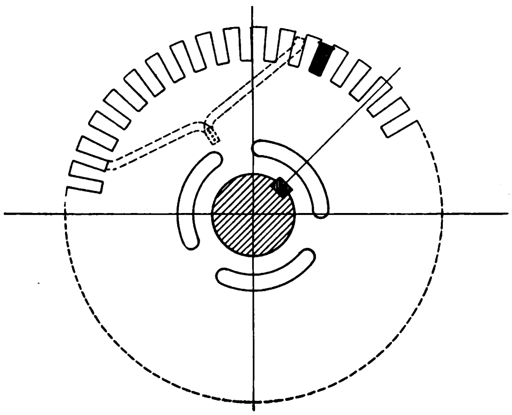
**Motor complete, showing Axle Brackets and Pinion.**

**Fig. 27.**



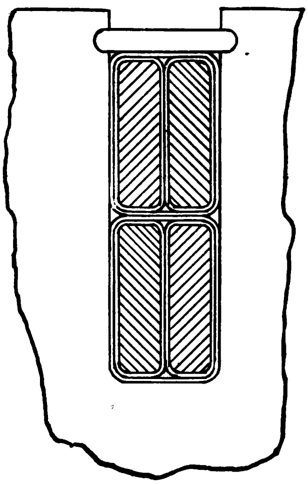
**Railway Motor complete, showing Pinion and Suspension Lug.**

Fig. 28.



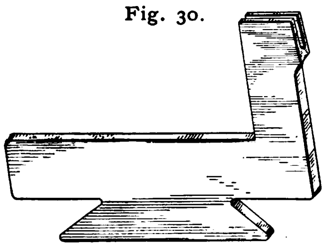
**A Single Armature Plate.**

Fig. 29.



**Section of Slot in Armature.**

Fig. 30.



**A Single Segment of Commutator.**

On top of the motors is provided a sliding or hinged lid, through which the armature and commutator can be reached. In the bottom field hand-holes are provided for taking out accumulations of dust. In all cases the upper field magnets can be removed without interfering with the armature or the lower field, and the armature can be removed by simply removing the top field. A lifting ring is provided in the top field, to which a crane hook can be attached. The motors are supported rigidly on the axle on one side, and to the frame of the trucks or locomotive above the springs on the other. This insures a proper distribution of the weight of the motor on the truck, and relieves the axle from unnecessary dead load.

# Why an Electric Motor Revolves.

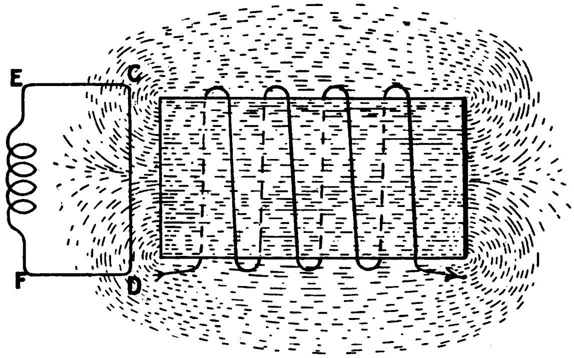
The action of the current in producing rotation in an electric motor is quite simple. While many electrical problems are comparatively complicated, the principal elements in the operation of electric railway apparatus may be readily understood.

The fundamental fact is the relation between an electric current and a magnet. If a piece of iron be surrounded by a coil through which current is passed, it becomes a magnet. In Fig. 31 the passage of a current through the coil of wire around the iron bar in either direction, renders the iron a magnet, with all the well-known properties of a magnet. It will attract iron, and the space surrounding it becomes magnetic. Iron filings will arrange themselves in the direction shown by the dotted lines in the figure. One end of the magnet is a north pole and the other a south pole.

If a wire, such as *CD*, be moved past either pole of the magnet, there will be a tendency for current to flow in the wire either from *C* to *D* or from *D* to *C*, according to the character of the pole past which it is moved and to the direction of the movement. If the ends of the wire *CD* are joined by a conductor, so that there is a complete circuit, a current of electricity will flow through the circuit. This circuit may be either a simple wire, as shown by the line *CEFD*, or it may be the windings on machines enabling the current to produce mechanical work, or it may be electric lamps producing light. The essential feature is that there shall be a complete path from *C* to *D* for the current to flow, no matter how complicated the circuit may be.

The reason why there is a tendency for an electric current to flow in the wire *CD* when it is moved in the vicinity of a magnet is not known. There are several theories, all more or less involved and depending upon pure assumptions as to the nature of an electric current. For all practical purposes it matters not what the reason is; the fact that current flows

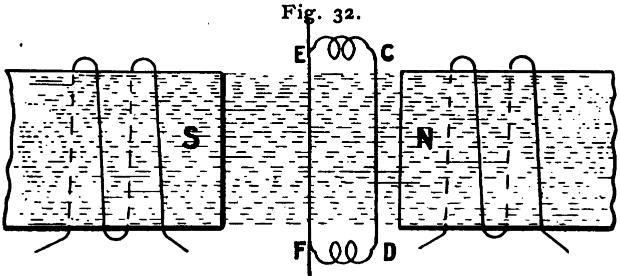
**Fig. 31.**




66

**Elementary Wire and Magnet, showing how Current is Produced.**

**Fig. 32.**




70

**Elementary Dynamo.**

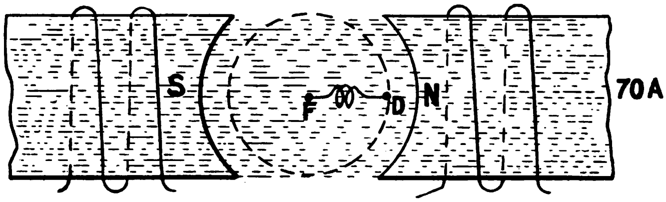
when there is an electric pressure in a closed circuit, is the important thing, and it serves all useful purposes to know that current does flow, and that its direction and amount are always the same under similar circumstances. There are many facts in mechanics that are accepted and used practically about which little is known as to the fundamental and primary causes, and this fact about motors and dynamos is, therefore, only one of many which all must accept without a full and complete explanation.

The intensity of the electric pressure, or electromotive force, depends upon the velocity of revolution of the wires and upon the strength of the magnets, and the quantity of current depends upon the electro-motive force and upon the amount of the resistance in the circuit. Other things being equal, the current through a long small wire, or greater resistance, will be less than through a short thick one, or a less resistance.

Having seen that when a wire is moved in the vicinity of a magnet an electric pressure is produced which will cause a current to flow in a closed circuit, one can easily conceive of many ways in which a current of electricity may be generated by combining magnets and wires so that there will be a relative motion between them. In order to make a continuous flow, the relative motion must be continuous; and if the current is to be uniform, the motion must be uniform.

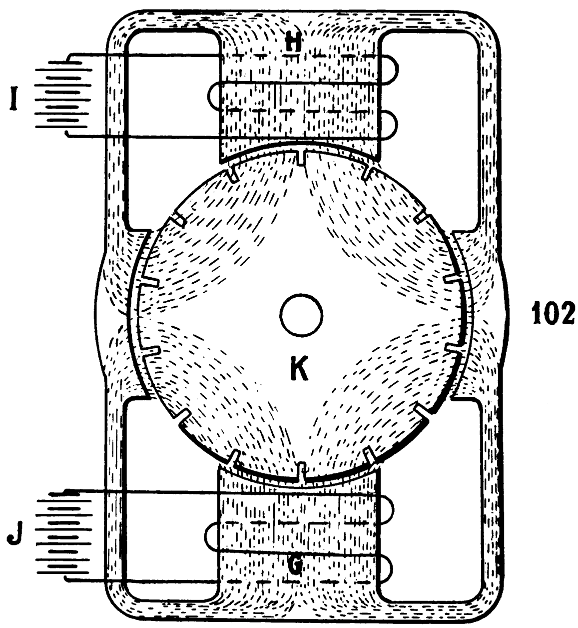
Two electro-magnets are shown in Fig. 32, in which the north pole of one magnet is near the south pole of the other, and the magnetic field between the two lies in approximately straight lines between the two magnets, as indicated by the dotted lines. If the wire *CD* be moved across this field and its ends be joined, as by the dotted circuit *CEFD*, a current will flow in this circuit. The wire *CD* may be made to revolve around the wire *EF*, passing in front of one pole and then in front of the other pole, as in Fig. 33. The current in the circuit will pass in one direction when the wire is passing one pole, and in the other direction when it is passing the other pole. The connection between this elementary arrangement and the dynamo is easily recognized. In the dynamo a mag-

Fig. 33.




**Elementary Diagram, showing the Magnetic Circuit between an Armature and a Pole Piece.**

Fig. 34.




**Elementary Dynamo.**

netic field is produced by electro-magnets called "field poles," and a considerable number of wires similar to the wire *CD* are placed upon an armature so that they revolve in front of the poles. Each individual wire produces current first in one direction and then in another direction, as explained above; but if there be many wires, there will always be the same number in front of the north, or positive, pole and the same number in front of the south, or negative, pole, so that the total or resultant action is practically uniform and may be made to produce a continuous current. Such a machine is the common dynamo or motor.

A dynamo transforms mechanical into electrical energy, and a motor transforms electrical into mechanical energy. The two operations are reversible and may be effected in the same machine: a dynamo may be used as a motor or a motor may become a dynamo. A machine is a motor when it is driven by a current of electricity, and it is a dynamo when it is driven by mechanical power and produces an electric current. If a motor be driven by an engine, it can deliver a current of electricity which is able to operate other motors or electrical apparatus or lights. A simple form of electric machine is shown in Fig. 34, which is the general form of the electric motor. In this there are two projections of steel, *H* and *G*, which are made electro-magnets by the current going through the wires wound around them from any source of electricity, such as a battery at *I* and *J*. These magnets have poles facing toward a drum, *K*, revolving on a shaft. The poles *G* and *H* are called the "salient" poles; the poles *M* and *P* are called the "consequent" poles. The magnetic flow or field is shown by the dotted lines. On the periphery of the drum are arranged wires in the slots shown. As this drum is revolved, there will be a tendency for electricity to flow in the wires. In order to get a current of electricity from these wires it is necessary to make a complete circuit. As each of the wires in the slots passes in front of a pole, a pressure or electro-motive force will be generated, and its direction will depend upon whether the pole is a north or a south pole.

The pressure or electro-motive force generated in the wires moving in front of the positive or north field poles will be in one direction, while those in front of the negative or south poles will be in the opposite direction. Therefore, if two such wires be connected together at one end of the armature, the free terminals of the wire at the other end of the armature will have the sum of the electro-motive forces generated in the two wires. The wires so connected can be considered as a turn of a single wire, instead of two separate wires, and this turn may be connected in series with other turns, so that the resulting electro-motive force is the sum of that in all the turns and all the wires so connected. It is customary to connect the coils of an armature so that the electro-motive force given is that obtained from half the coils in series. The other half of the coils is connected in parallel with the first half, so that the currents flowing in the two halves will unite to give a current in the external circuit equal to twice the current in the two armature circuits or paths.

It is evident that, as the armature revolves, wires which were in front of the positive pole will pass in front of the negative pole, and that in order to maintain the electro-motive force it will be necessary to change the connections from the armature winding to the external circuit in such a way that all the wires between the two points of connection will have their electro-motive forces in the proper direction. The connection to the armature must therefore be made not at a definite point in the armature itself, but at a definite point with reference to the field magnets, so that all the wires between two points or contacts shall always sustain the same relation to the field magnets.

For this purpose a device known as a "commutator" is provided. The commutator is made up of a number of segments, as shown at *A*, in Fig. 35, which are connected to the armature winding. On the commutator are sliding contacts, or brushes, which bear on the segments and are joined to an external circuit, making a continuous path through which current may flow. As the commutator revolves the different segments come under the brushes, so that the relative position of the armature

Fig. 35.

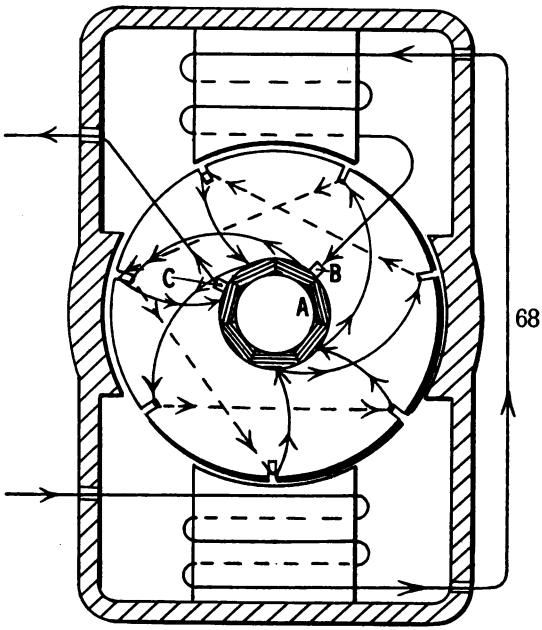



**Diagram showing the Elements of the Wiring of Motor with Consequent Poles.**

wires between the brushes is dependent on the position of the brushes. The armature wires which connect the brushes are those sustaining the desired definite position to the field magnets, so that the currents from the armature at all times flow properly into the external circuit, although individual armature wires carry currents first in one direction and then in the other direction, depending on the character of the pole in front of which they may be moving.

On two-pole machines there are two brush-holders, each containing one or more brushes. On the four-pole machine there may be either two or four brush-holders, and on a six-pole machine, either two, four, or six brush-holders.

A single path of the current through the commutator and armature winding is shown by the arrows on Fig. 35. The brushes *B* and *C* are placed on the top side of the commutator to make them more accessible, and this gives a peculiar but simple armature winding.

For the sake of simplicity, the batteries *I* and *J*, of Fig. 34, are not used on common forms of generators or motors, but the current that flows from the armature through the commutator is made to flow through the electro-magnets either in whole or in part. If all of the armature current flows around the electro-magnets or fields of the machine, it is a "series" machine; if only a part of the current is used in this way, it is a "shunt" machine; that is, some of the current is "shunted" through the fields. Sometimes both the shunt and series windings are used, and in that case the machine is called a "compound wound" machine. Such a machine has a large wire through which the main current passes, and a fine wire through which the shunted current flows. Fig. 35 shows how the commutator and the fields are connected, and how the current flows from the wires in the armature through the commutator in a series machine.

If the current delivered by a dynamo does not flow in the desired direction, it can be reversed by shifting the wires in the binding posts or by throwing a switch. If the motor does not revolve in the desired direction, it can be made to do so by reversing the connections to the armature or field-coils; so that,

without knowing which way a current of electricity is to be generated, any practical man can make a motor revolve in a proper direction by simply changing the connections.

It is natural that a machine which gives out electric energy when driven by an external power, will, when electric energy is delivered to it, reverse its action and give out mechanical power and do work. This is not a logical reason why a motor revolves under the influence of an electric current, but it is a natural inference which assists in comprehending the fact.

Perhaps the simplest way to explain the cause of the movement of an electric motor, when supplied with a current, is to compare the action to the well-known attraction of unlike poles or magnets and the repulsion of like poles. Unlike poles are north and south; like poles are two north or two south. In any motor the current through the field causes a north or south pole to be maintained, and the current through the armature and brushes causes an opposite polarity. These constantly maintained unlike poles attract each other and pull the armature around on its axis.

It has been explained that if a motor be driven by a belt an electro-motive force is produced and the machine acts as a dynamo. It is also a fact that an electro-motive force is produced whether the power for driving the machine is obtained from a belt or from the electric current,—that is, whether the machine be driven as a dynamo or as a motor. In a dynamo, however, the current flows out in the direction in which the electro-motive force is acting. In a motor the electro-motive force produced has a direction opposed to the direction of the flow of current. This may be illustrated by the following experiment:

Two similar machines are driven independently at 600 revolutions and give an electro-motive force of 100 volts. Similar terminals of the two machines are connected together. No current flows between the machines because the two pressures are the same and are opposed in direction. If now the belt be thrown off from one machine its speed will begin to fall. This will lower its electro-motive force below that of the other

machine or dynamo, but will not change the direction of the force. There will now be a difference of pressure in favor of the machine which is driven, and it will now send a current through the other machine and run it as a motor. The speed of the motor will continue to fall until the difference in pressure or electro-motive force between the two machines is just sufficient to cause the flow of enough current to keep the motor running against whatever frictional resistance and other resistance there may be. The electro-motive force generated in the motor, which is against or counter to that of the current in the circuit, is called the "counter electro-motive force."

In order to determine how fast a motor will run without doing work under any given pressure, it is not necessary to know anything about the dynamo that furnishes the pressure. The pressure alone is sufficient to determine the speed of the motor. For instance, if a motor will give a pressure of 500 volts when running free at 100 revolutions, it will always run at about 100 revolutions when not doing work on any electric circuit where the pressure is 500 volts.

This description of a motor or dynamo carries with it all of the fundamental theory of electrical generators and motors that it is necessary for a mechanic to know in order to take reasonably intelligent care of electric locomotives. Further useful knowledge must be attained by studying the different types of electric motors and dynamos. These other types all have the same fundamental theory, even when the construction is quite different. It has been the aim in devising these electric locomotives to adhere as closely as possible to a uniform type for all sizes, so that when a mechanic has once grasped the fundamental design of one size he will be familiar with the other sizes.

# Characteristic Curves of Motors.

Five characteristic diagrams—Figs. 36 to 50—are given for each size of motor. The first three diagrams show the electrical horse-power, brake horse-power, torque, efficiency, and speed for different currents in amperes flowing into the motors and with line pressures of 500, 250, and 125 volts. The fourth characteristic diagram shows the relation between speed and pressure for various currents and corresponding torques. The fifth characteristic diagram shows the relation between torque and speed for different pressures and the relation between the current in amperes and the speed for same pressures.

The following is an example of the use of the diagrams that follow :

What horse-power will be required to haul a train weighing 500 tons up a two per cent. grade at a speed of twenty miles an hour on a good track ?

From Fig. 62 the pull required to haul 500 tons on a level is 3500 pounds, taking the friction at 7 pounds per ton, which is a fair allowance for a good outside track. For a little higher speed and best track the resistance might be as low as 5 pounds a ton.

From Fig. 64 the resistance per ton on a two per cent. grade is found to be 40 pounds ; therefore, the resistance for 500 tons would be 20,000 pounds. The total is 23,500 pounds, or the draw-bar pull required.

From Fig. 66 it is found that 23,500 pounds draw-bar pull at twenty miles an hour requires approximately 1,250 horse-power. This must be the safe output of the motors. In making these calculations the total weight of the train, including the locomotive, should be used, otherwise an additional amount of power must be added to include that required by the locomotive.

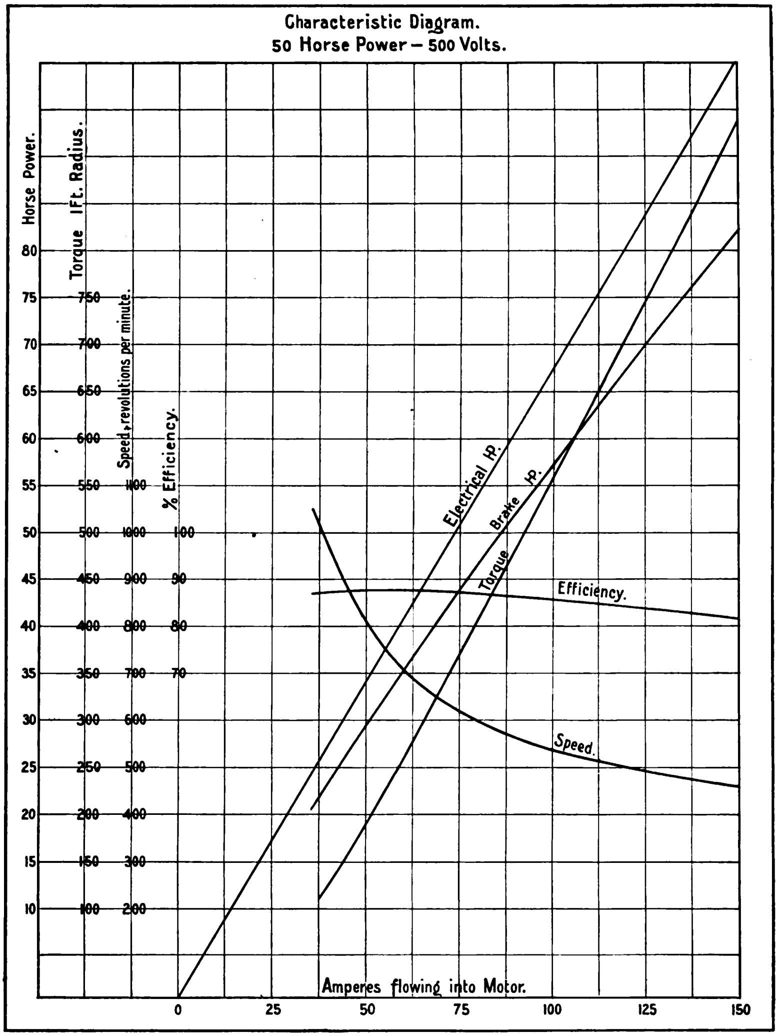
Fig. 67 gives the speed in miles an hour for all common sizes of drivers and for a variety of armature speeds and gear ratios. For instance, if the armature speed is 1000 revolutions per minute and the gear ratio is 1 to 2, the axle will revolve 500 times per minute. If the diameter of the drivers is 36 inches, the speed will be about 54 miles an hour.

Fig. 67 also serves to find the proper gear ratio where the speed of the train, the revolutions of the armature and diameter of the drivers are given. For example, at a speed of 80 miles an hour and a 68-inch driving-wheel, the axle will revolve 400 times per minute, and the proper gear ratio will be between 1 to 2 and 1 to 3, or about 1 to 2½ when the armature velocity is 1000 revolutions per minute.

Fig. 65 gives the number of revolutions per mile of drivers of different diameters and the circumferences of the driving-wheels in feet. This diagram is found useful to determine the speed of axles and the distance which the locomotive will advance by each revolution of the drivers.

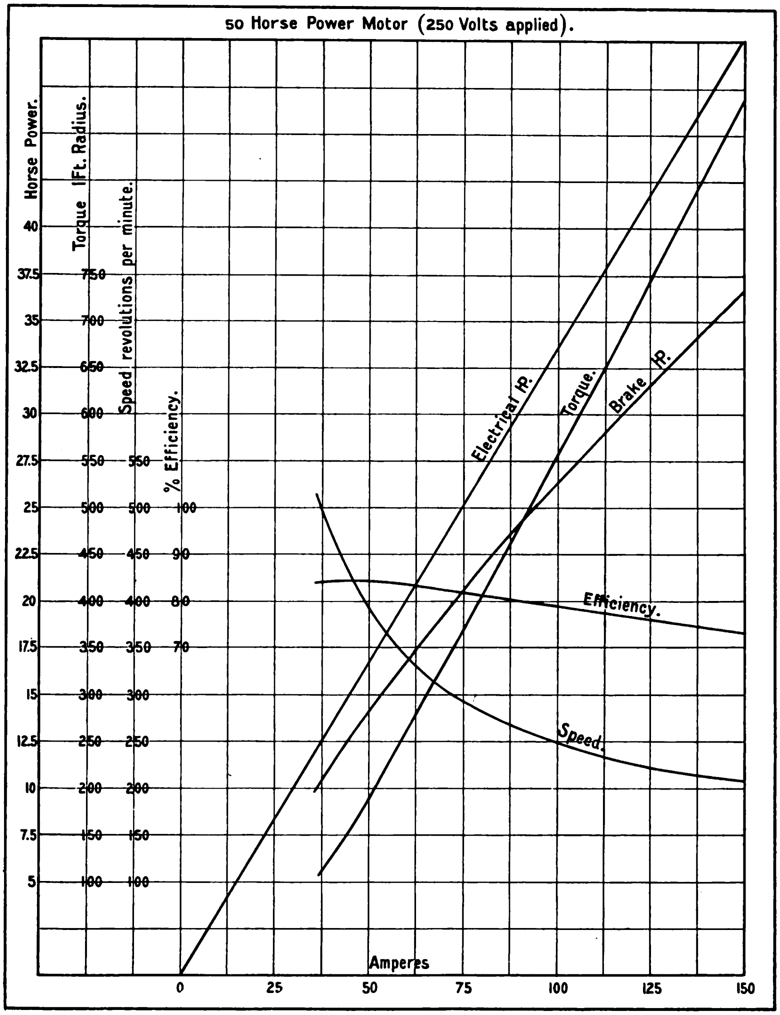
Fig. 61 shows the weight on drivers required to get a given draw-bar pull under different conditions. For example, to get 15,000 pounds pull under the best conditions requires only 50,000 pounds on the drivers, while with bad rails 100,000 pounds is necessary.

Fig. 36.



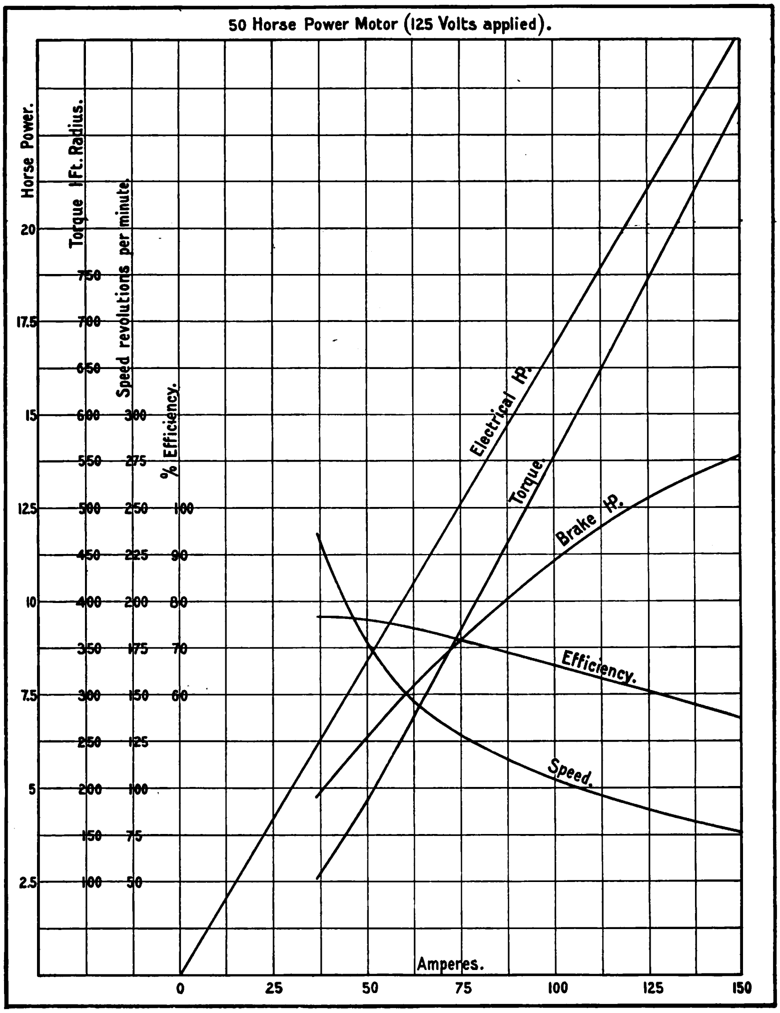

**Horse-Power, Torque, Speed, and Efficiency Diagram, at 500 Volts for the 50 H.-P. Consequent Pole Motor.**

**Fig. 37.**




**Horse-Power, Torque, Speed, and Efficiency Diagram, at 250 Volts for the 50 H.-P. Consequent Pole Motor.**

Fig. 38.




Horse-Power, Torque, Speed, and Efficiency Diagram, at 125 Volts for the 50 H.-P. Consequent Pole Motor.

**Fig. 39.**

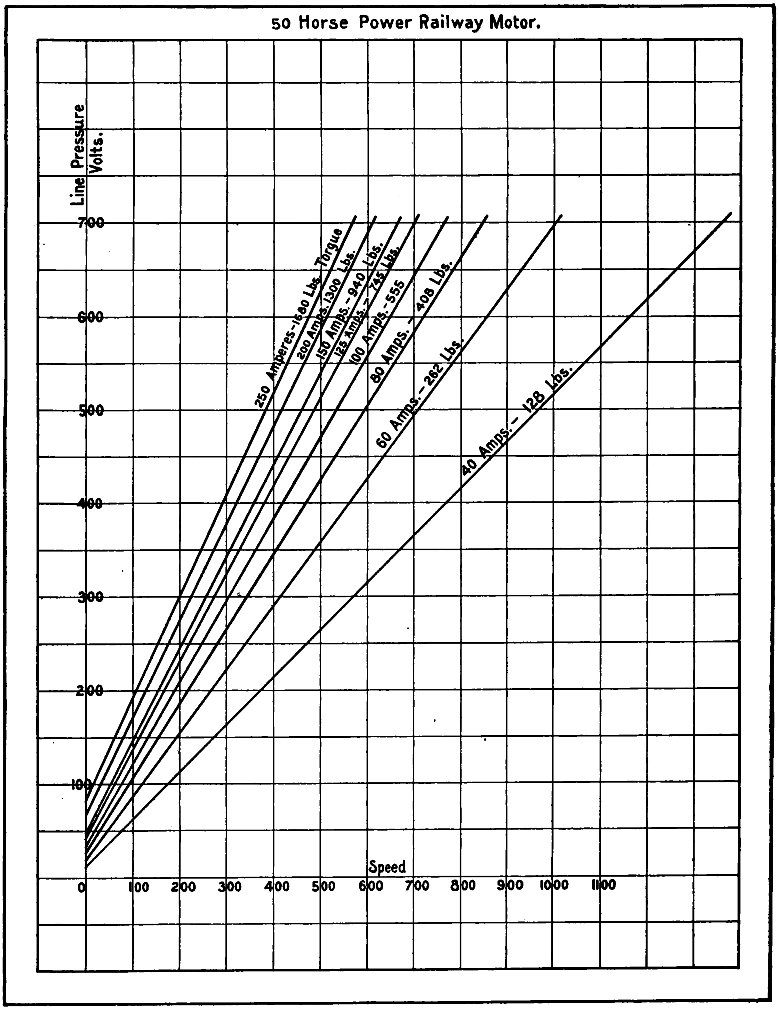
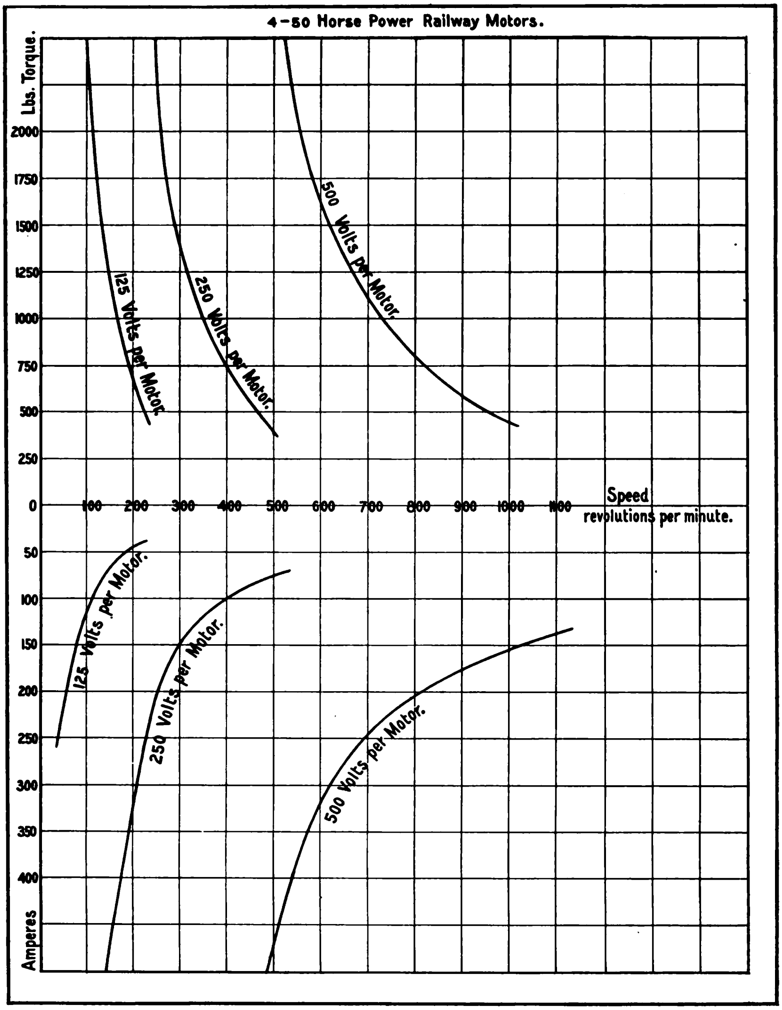


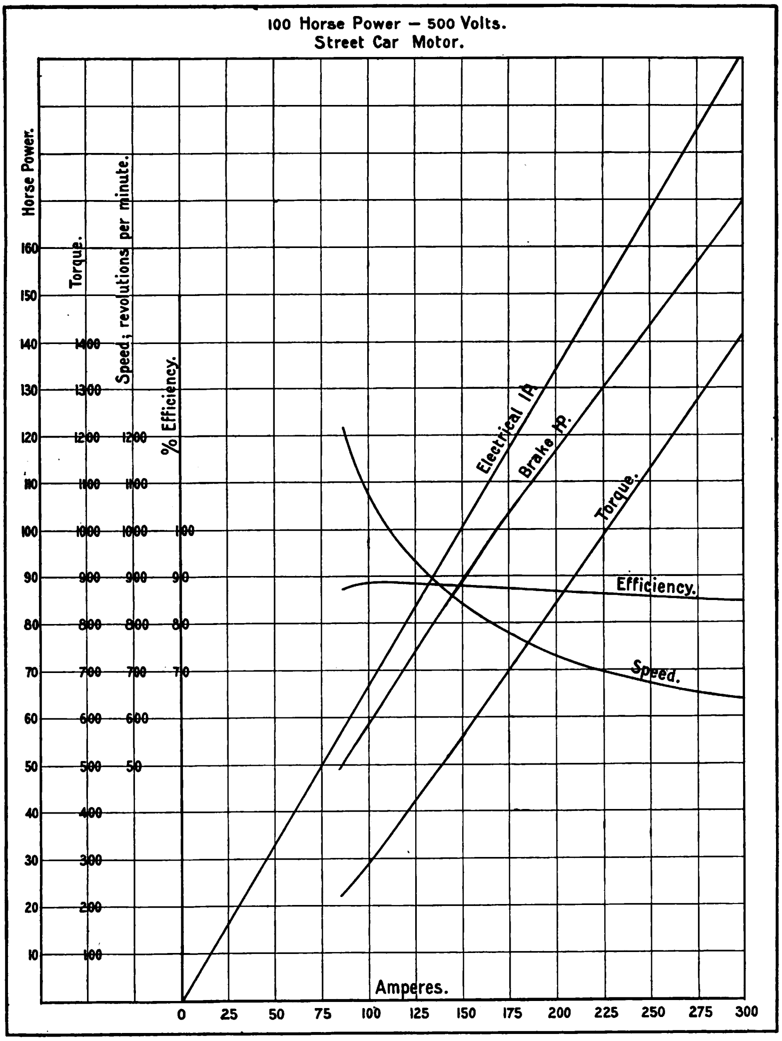

**Diagram showing the Torque, Speed, and Current at Different Line Pressures for 50 H.-P. Consequent Pole Motor.**

Fig. 40.



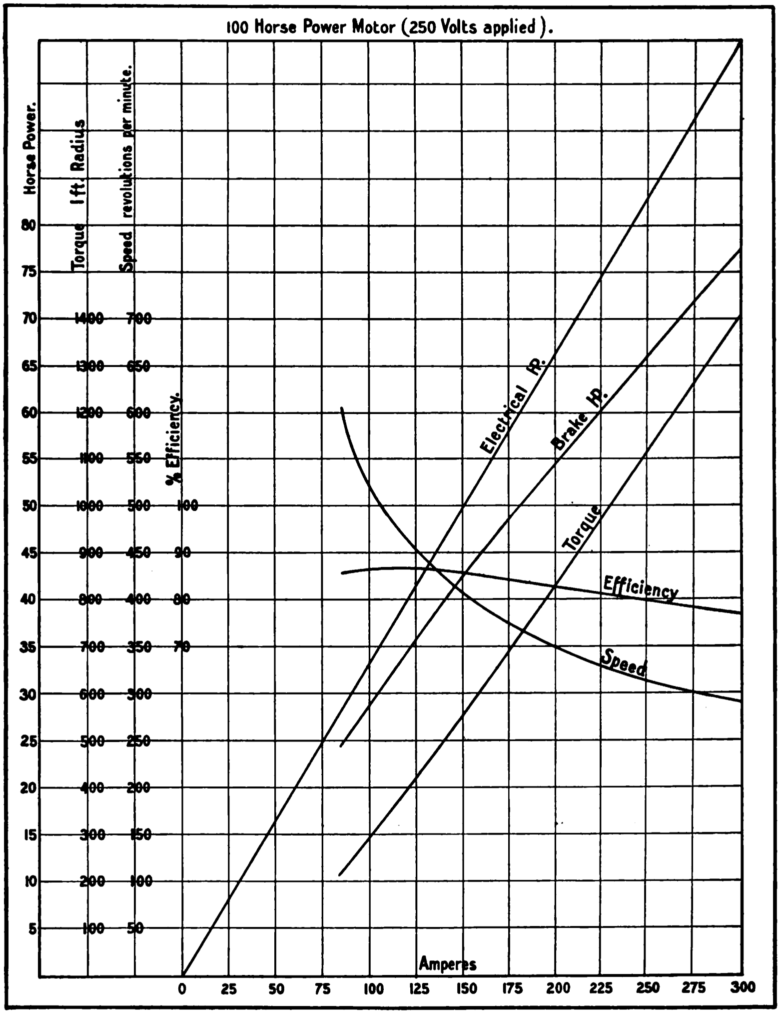

Torque, Current, and Speed Diagram, with Four Series, Two Series, and Multiple Arrangements, 50 H.-P. Consequent Pole Motor.

Fig. 41.



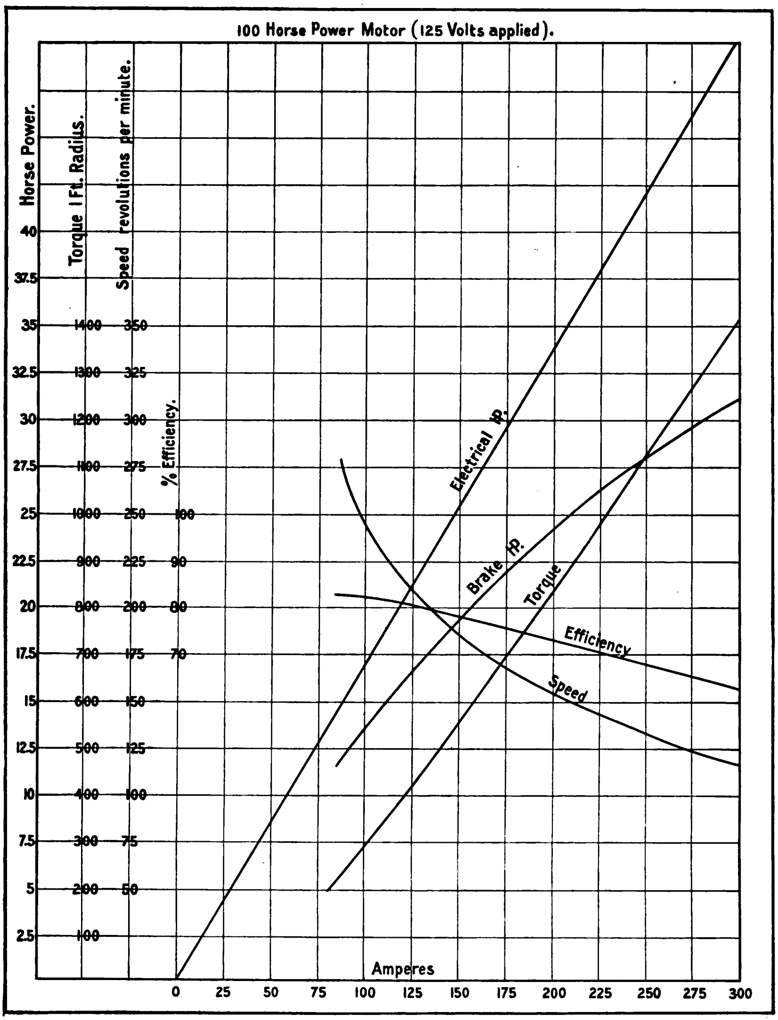

**Horse-Power, Torque, Speed, and Efficiency Diagram, at 500 Volts for the 100 H.-P. Consequent Pole Motor.**

Fig. 42.




Horse-Power, Torque, Speed, and Efficiency Diagram, at 250 Volts for the 100 H.-P. Consequent Pole Motor.

Fig. 43.




**Horse-Power, Torque, Speed, and Efficiency Diagram, at 125 Volts for the 100 H.-P. Consequent Pole Motor.**

Fig. 44.

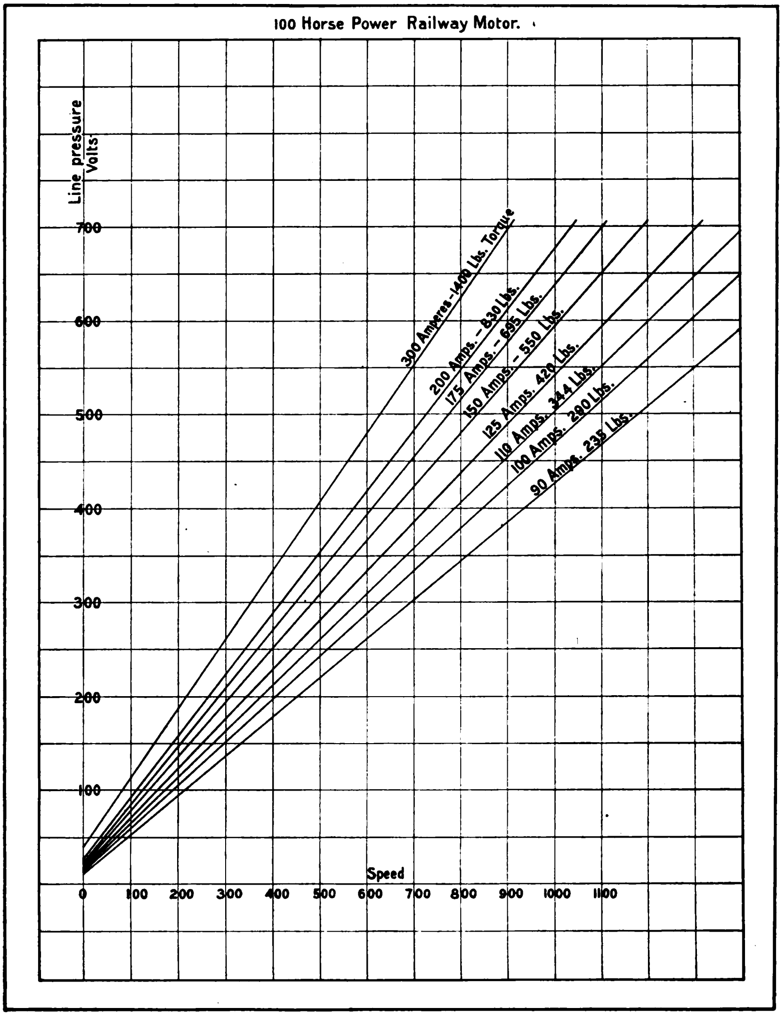
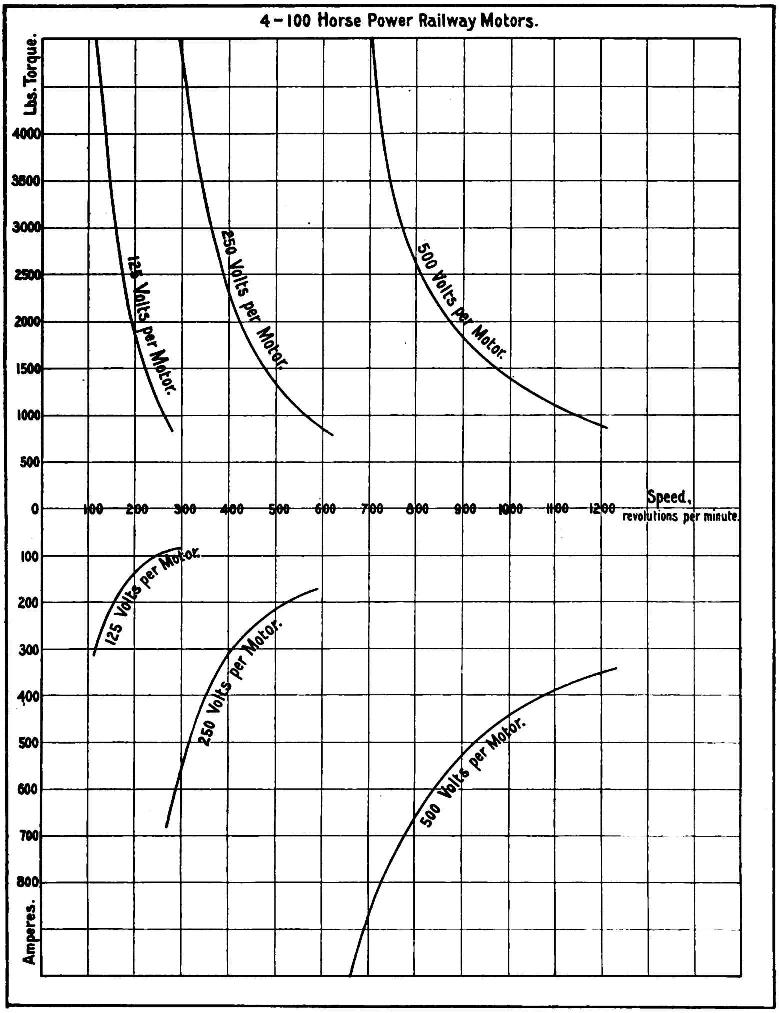


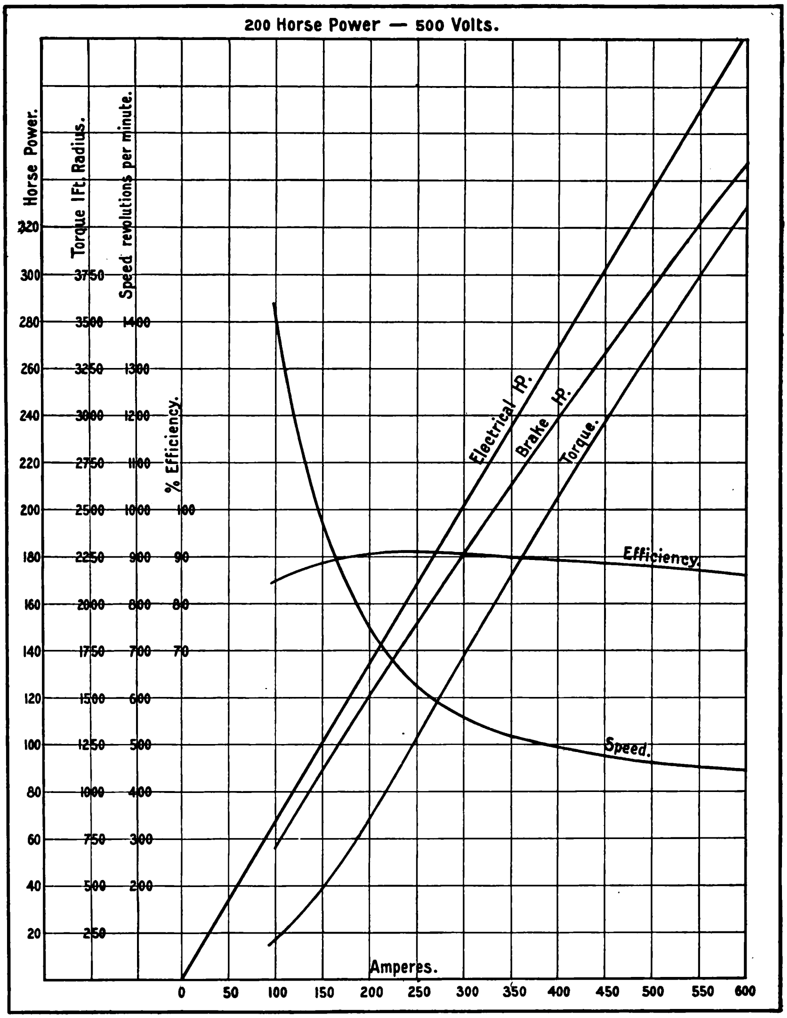

Diagram showing the Torque, Speed, and Current at Different Line Pressures for 100 H.-P. Consequent Pole Motor.

Fig. 45.



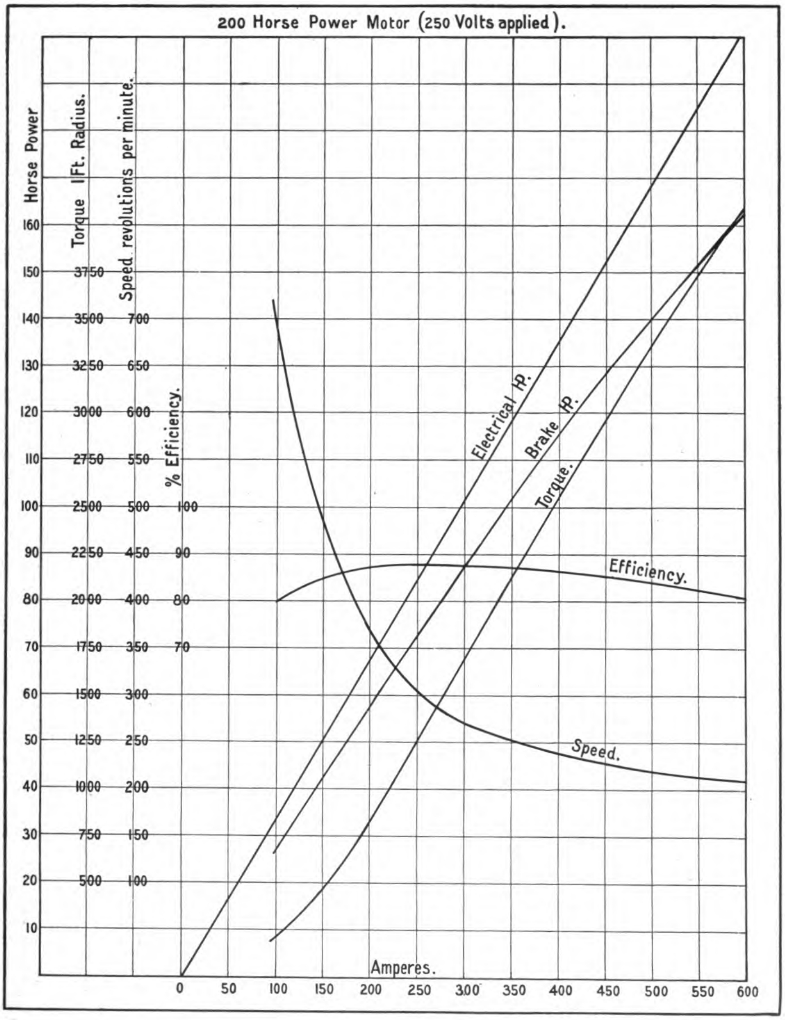

Torque, Current, and Speed Diagram, with Four Series, Two Series, and Multiple Arrangements, 100 H.-P. Consequent Pole Motor.

Fig. 46.



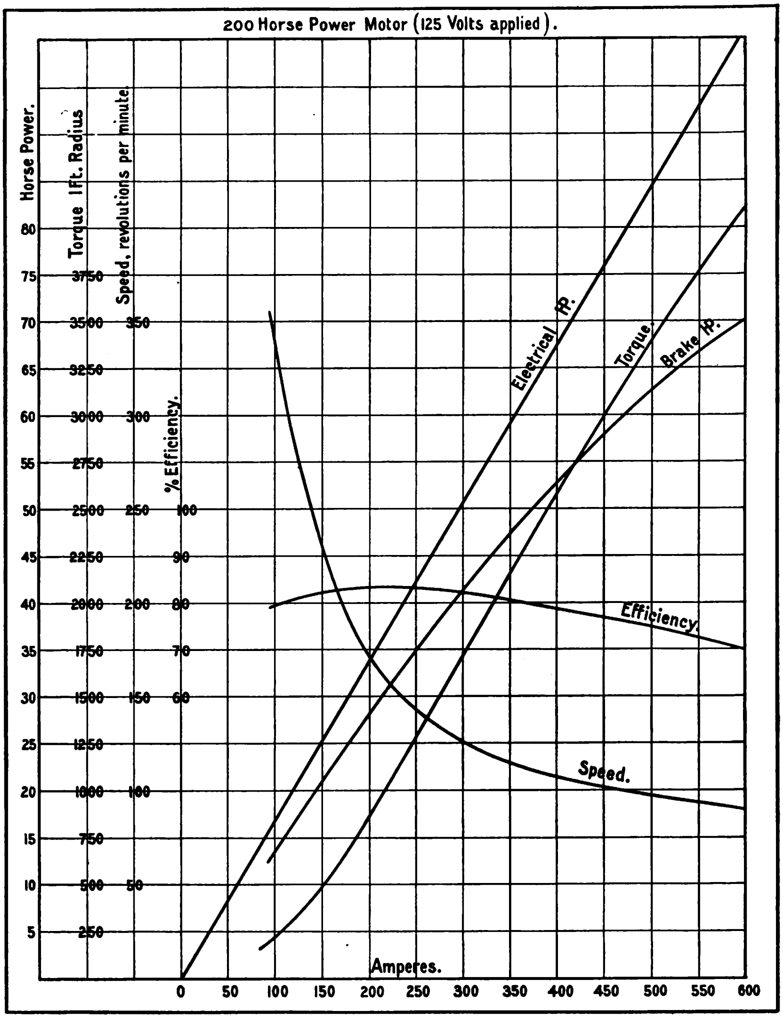

Horse-Power, Torque, Speed, and Efficiency Diagram, at 500 Volts for the 200 H.-P. Consequent Pole Motor.

**Fig. 47.**




**Horse-Power, Torque, Speed, and Efficiency Diagram, at 250 Volts for the 200 H.-P. Consequent Pole Motor.**

Fig. 48.




Horse-Power, Torque, Speed, and Efficiency Diagram, at 125 Volts for the 200 H.-P. Consequent Pole Motor.

O. B. Mitcham,
Captain of Ordnance,
Comd'g



Fig. 49.

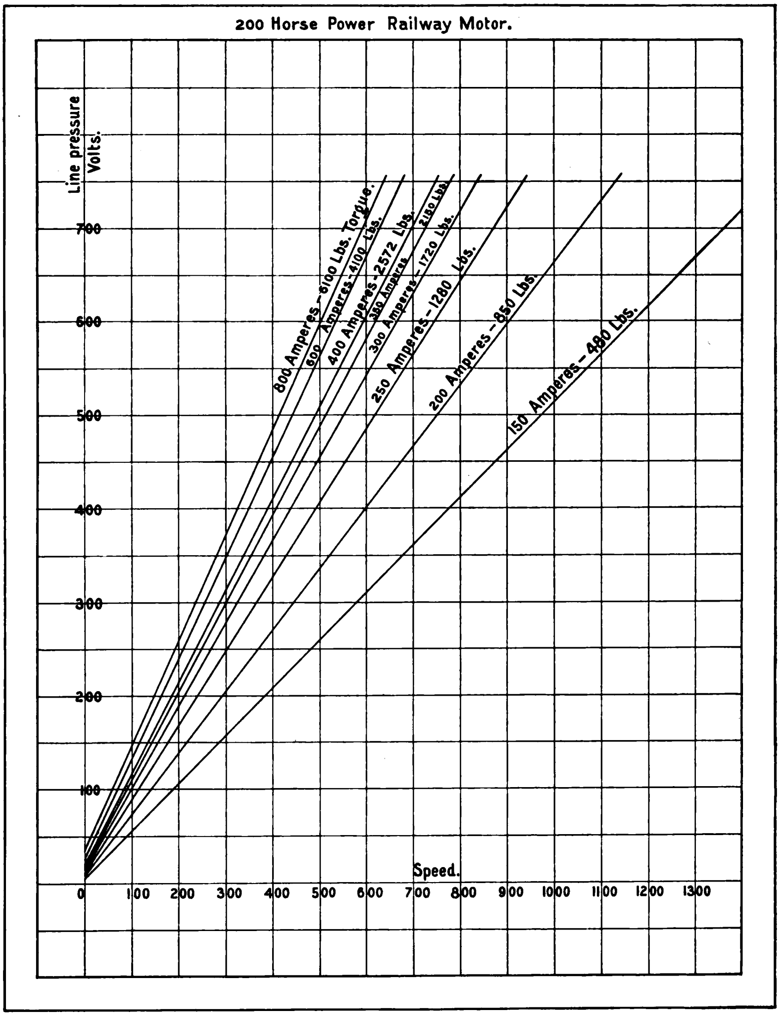
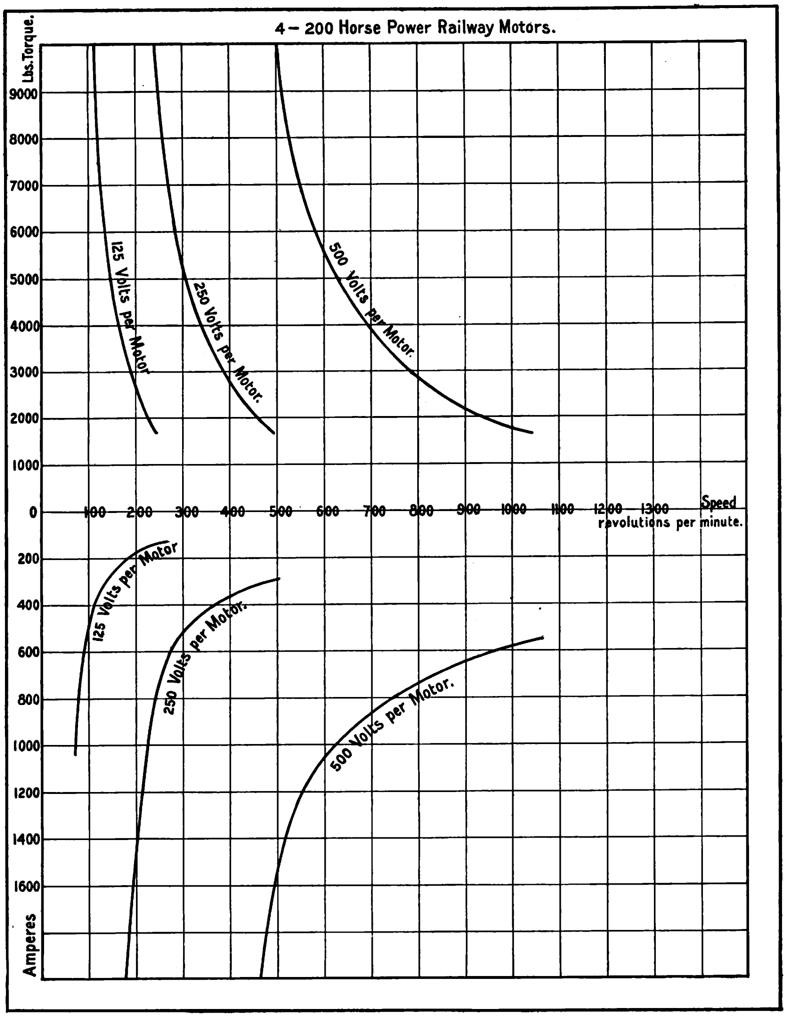



**Diagram showing the Torque, Speed, and Current at Different Line Pressures for 200 H.-P. Consequent Pole Motor.**

Fig. 50.




Torque, Current, and Speed Diagram, with Four Series, Two Series, and Multiple Arrangements, 200 H.-P. Consequent Pole Motor.

# Some Simple Problems in Electric Locomotive Service.

The use of the curves for determining the operation of the motor under certain conditions is illlustrated in the following examples from the 100 horse-power motor :

**Example 1.** Under what conditions does the 100 horse-power motor develop its rated horse-power on a 500 volt circuit?

On Fig. 41 the horizontal line through 100 on the horse-power scale intersects the curve marked "brake horse-power" on the vertical line passing through 165 amperes. The corresponding electrical horse-power found in the same vertical line is 113, which is the energy received by the motor. The corresponding efficiency on the same vertical line is 88 per cent., the speed is 780, and the torque 670 pounds at one foot radius. Figs. 42 and 43 indicate the conditions when the line pressure is 250 or 125 volts.

**Example 2.** Under what conditions does the 100 horse-power motor on a 250 volt circuit develop a torque of 670 pounds at one foot radius?

On Fig. 42 the torque 670 corresponds to 165 amperes, or the same current, and to a speed of 360, an efficiency of 84 per cent., a brake horse-power of 47½, and an electrical horse-power of 57. Figs. 41 and 43 give similar data for 500 and 125 volts pressure.

**Example 3.** If a torque of 1000 pounds is required on each 100 horse-power motor, what speed will be developed if the four motors are in series,—that is, with 125 volts on each motor?

Referring to Fig. 43 and following the horizontal line through 1000 on the torque scale to the vertical passing through the curve of torque, it is seen that the corresponding speed is 140 revolutions.

**Example 4.** Suppose the pressure to be 500 volts, and the speed of the 100 horse-power motors 780 revolutions per minute when exerting a torque of 700 pounds for each motor in multiple :

If the pressure be raised to 600 volts, the speed can be determined by the diagram, Fig. 44. It is seen that the speed has increased to over 900 revolutions per minute. If the pressure is decreased instead of increased, the diagram also shows the speed at which the motor will exert the same torque.

**Example 5.** Suppose the speed to be 780, the torque 700 pounds, and the voltage 500, what will be the speed if the load is decreased until the torque is 420 pounds?

From the diagram, Fig. 44, it is seen that the speed will increase to 925 revolutions per minute. The speed increases as the load decreases, and *vice versa.*

**Example 6.** If two motors are revolving at 780 revolutions per minute under an electric pressure of 500 volts, and each exerting 700 pounds torque, what will be the speed in case they are connected up in series,—that is, so that the current goes first through one and then through the other?

The answer is found to this by inspecting the diagram, such as Fig. 42, remembering that with two motors arranged in series, the electric pressure is divided between them, and the real pressure for each motor in but one-half of the total line pressure, or 250 volts. If there were three motors, it would be but 166 volts, and if four motors in series, 125 volts. It is seen that the speed with two motors in series will be 370 when the torque of each is 700 pounds.

This question is one that often arises in running electric locomotives, for the reason that it is frequently necessary to run the motors in series in order to reduce speed without putting resistance in the circuit.

For cases of this kind, when there are four motors, see Fig. 45.

**Example 7.** At a speed of 900 revolutions, what is the current flowing when four 100 horse-power motors are connected in multiple to a 500 volt circuit, and what torque is developed?

On Fig. 45 the vertical line passing through 900 on the speed scale intersects the 500 volt curve at the horizontal, passing through 520 on the ampere scale on the lower part of the diagram, and intersects the 500 volt curve on the horizontal, corresponding to 1850 on the scale of torque on the upper part of the diagram.

On Fig. 41 the current corresponding to a speed of 900 revolutions is 130 amperes, which is the current for one motor. Multiplying this by 4 gives 520 amperes, which corresponds with the result from Fig. 45.

**Example 8.** If a 100 horse-power motor develops a torque of 550 pounds at a speed of 700 revolutions, what electromotive force is required on the circuit?

On Fig. 44 the intersection of the vertical line through 700 revolutions intersects the curve of 550 pounds torque on the line corresponding to 425 volts.

**Example 9.** What resistance will be required in series with the 100 horse-power motor, in order to give a torque of 550 pounds at 700 revolutions and 425 volts pressure, if pressure be 500 volts?

The voltage required by the motor is 425. The current corresponding to 550 pounds torque is 150 amperes (see Fig. 41). The resistance must be sufficient to reduce the electromotive force from 500 volts on the line to 425 volts on the motor, when 150 amperes is flowing through it. 75, the number of volts to be taken up by the resistance, divided by 150, the number of amperes flowing, equals one-half, or the number of ohms required in the resistance.

**Example 10.** Suppose a rheostat be introduced into a circuit in which there is an electric motor running at a given speed and giving a fixed torque or pull, what will be the effect of the resistance on the speed?

Suppose the electric pressure be 500 volts, the torque 550 pounds, the speed 840 revolutions, and a resistance of one-half ohm be put into the circuit. The current to give 550 pounds torque is 150 amperes (see Fig. 44). The drop in pressure due to the resistance is 150 times $\frac{1}{2}$, or 75 volts. Taking this drop in pressure from the 500 volts direct pressure, there remains 425 volts to act on the motor. The motor will now act just as if running on a circuit having a pressure of 425 volts. On Fig. 44 it is found that at 425 volts and 150 amperes the speed will be about 700 revolutions.

**Example 11.** Suppose a current of 150 amperes be flowing through a wire, what will be the loss if a resistance of one-half ohm is put into the circuit by cutting the wire and connecting therein a rheostat, diverter or resistance box, all of which are synonymous terms?

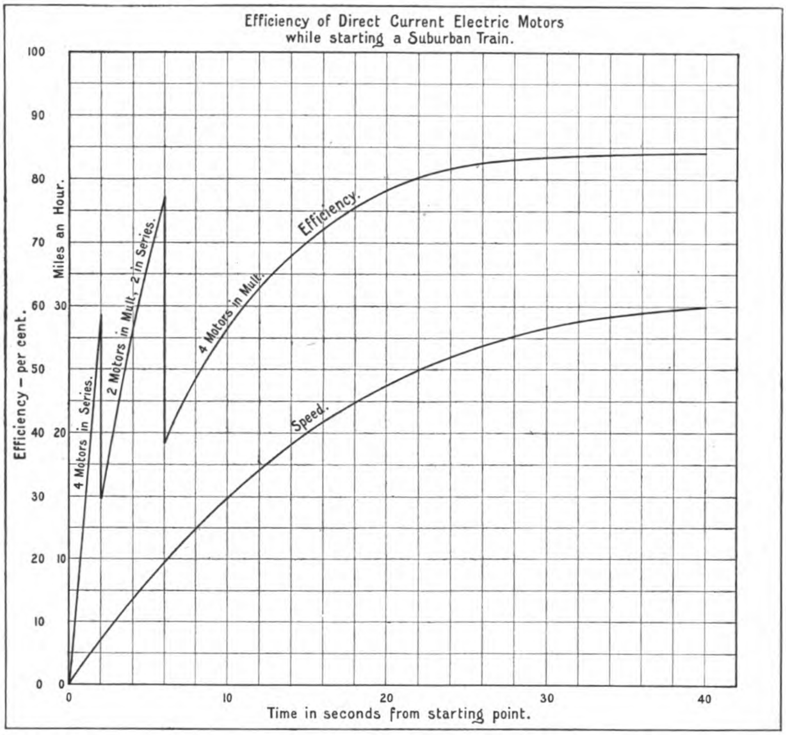
The lost power in watts due to putting the resistance in the circuit is found by multiplying the resistance in ohms by the square of the amperes of current flowing through the resistance. The loss in horse-power is found by dividing the watts by 746. In this case the loss is $\frac{1}{2} \times 150 \div 746$, or $\frac{1}{10}$ horse power.

NOTE.—The characteristic curves for the 50 horse-power and 200 horse-power motors will permit the easy solution of similar problems for locomotives equipped with those motors. All practical problems that commonly present themselves under regular service conditions can be solved by a study of the characteristic diagrams.

# Efficiency of Electric Locomotives.

The efficiency of a motor is the ratio between the mechanical energy delivered by its shaft and the electrical energy received by the motor from the circuit. Curves are shown giving the efficiency of the 50, the 100, and the 200 horse-power motors at 500 volts, 250 volts, and 125 volts, and at various speeds. The efficiency of the 100 horse-power motor when developing 100 horse-power at 500 volts, which is the condition of the normal full-speed running, is 88 per cent. between the electric circuit and the armature-shaft pinion. It is 89 per cent. at 60 horse-power, and 84.5 per cent. at 170 horse-power. At 250 volts, which is the condition when two motors are connected in series for about half-speed, the efficiencies for the corresponding torques vary between 86 per cent. and 77 per cent. At 125 volts, which is the condition on a 500-volt circuit when four motors are in series and the speed is low, the efficiency for corresponding torques varies from 83 to 62 per cent. The friction of the gears will reduce these figures about 3 or 4 per cent. for the efficiency between the armature-shaft pinion and the driving-axle. A resistance or rheostat is placed in circuit at the moment of starting and at intervals while the motor is being brought up to speed, and the efficiency is reduced while the resistance is in circuit. If the time of starting be short, the reduction in average efficiency due to the loss in resistance is small. The average efficiency between the electric circuit and the driving-axle will not, except in special cases, be less than from 70 to 85 per cent., depending upon the proportion of time at which the motor is run at slow speed. The general change of the efficiency of an electric locomotive during the starting of a train in suburban service is shown by Fig. 51.

Fig. 51.

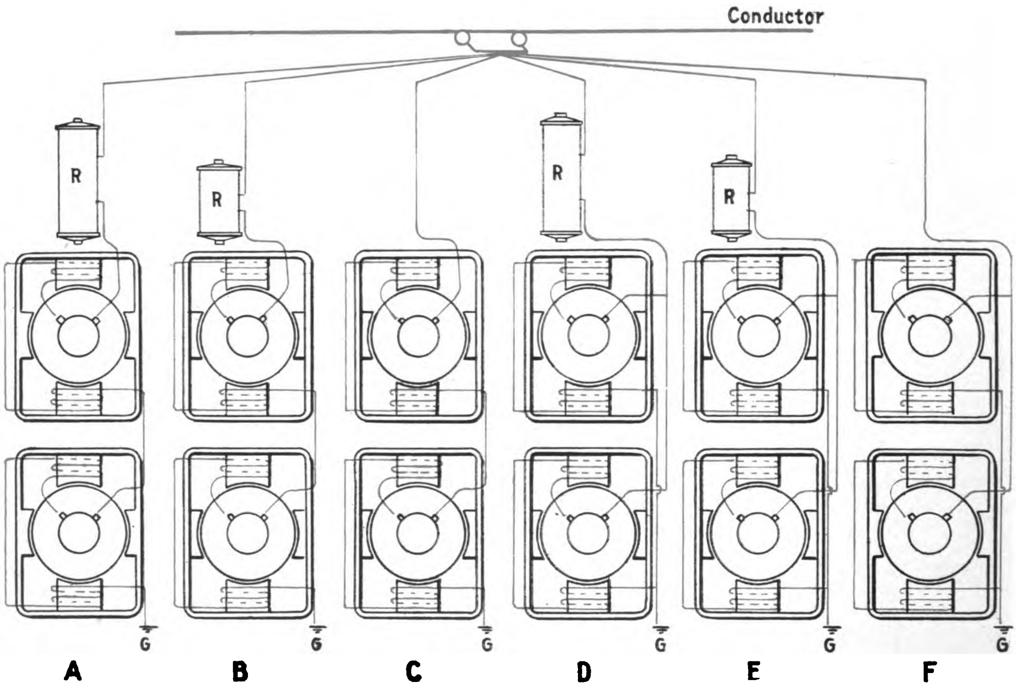



**Efficiency of Electric Locomotives while Starting Suburban Trains.**

# Controller.

A controller on an electric locomotive takes the place of the throttle and the reversing lever on the steam locomotive. It is a device for switching the current in different ways through the motors and through the resistances. In starting an electric locomotive, as in starting a steam locomotive, the direct current has to be choked or cut down just as the steam-pressure is choked or cut down by the throttle valve; that is, the electric current has to be throttled as well as the steam current. To do this on an electric locomotive, a considerable amount of resistance is provided in the shape of bands or strips of iron or nickel-steel arranged as has been described. This resistance is subdivided into a considerable number of parts, so that it can be cut down gradually, just as notches are provided on the throttle-lever quadrant. Instead of the notches, the resistance is provided with contacts, over which slide the movable switches which make the electric connection. It is the office of the controller to move these switches in the proper way. The controller is divided into two distinct parts; namely, the switches for the resistance and the switches for the motors. The resistance switches vary the resistance, as desired. The switches for the motors change the path of the current, so that it either divides and passes through the motors independently,—that is, in "multiple,"—or passes first through one motor and then the other, until it has passed consecutively through them all; this is called the "series" condition. The controller varies the resistances in the circuit and connects the motors either in series or multiple. The multiple condition is frequently called the "parallel" condition. From this has arisen the terms "series multiple" or "series parallel" controller. Controllers are generally provided with a "cut-out" switch, which cuts the current out of all the motors and all the resistances. It is found to save room if the switches in the controller are placed on a drum, so that as the drum revolves different combinations are made.

A simple diagram, showing how the controller connects the resistances and motors in starting a train and when running at different speeds, is shown by Fig. 52. The current flows from the conductor, or trolley wire, as shown by the arrows, first through a large amount of resistance at *R* on diagram *A*, then through the fields and armatures of all the motors as indicated by the red line, and thence to the ground return *G*. As soon as the locomotive has started, the current is switched by the controller so as to cut out some of the resistance, and it then flows through less resistance and through all the fields and armatures as before, as indicated by the diagram at *B*. When more speed is attained all the resistance is cut out, and the current flows through the fields and armatures of all the motors in series, as shown by the diagram *C*. This is the full series arrangement. The next step is to switch in all the resistance




**Elementary Controller Diagrams.**

again, as shown by the diagram at *D*, and arrange the circuits so that the current divides and goes through the motors independently, as indicated by the red lines. The next step is to cut out a part of the resistance, as indicated by the diagram at *E*, the current still passing through the motors independently, as before. Next, all the resistance is cut out, as indicated in the diagram at *F*, and this gives the full multiple or parallel position, in which there is no resistance in the circuit, and the current divides and passes through the motors independently.

When there are more than two motors, a similar plan is followed, and, where the work is heavy, four motors are often put in series at first, in the same way that two motors are indicated in series on the diagram *A*.

In the condition shown by the diagram *F*, the locomotive is arranged to run at its maximum speed. In the condition shown by the diagram *A*, it will give the maximum torque. The two conditions of maximum efficiency are when the motors are in full series, as at *C*, and in full multiple, as at *F*. The efficiency with the other arrangements depends upon the amount of resistance in the circuit. It is evident the controller must not be put into the multiple arrangement before some considerable speed has been attained; otherwise an exceedingly large amount of current will flow through the motors and overheat them and possibly burn out the armatures and field coils, and seriously injure the commutators. This is one of the ways in which a careless engineer can seriously injure an electric locomotive, even with the most perfect machinery. There is no way of guarding against this except by disciplining the engineers, any more than it is possible to guard against overheated crown sheets and other accidents in steam locomotives. It does not require so much intelligence to operate an electric locomotive as a steam locomotive, but in both machines caution and common sense must be exercised by the man in charge to prevent damage to the machinery.

An example of the danger to electric machinery by putting the controller in the multiple position with resistance cut out, before some considerable speed has been attained, is found with

the 100 horse-power motor in which the current should not be more than a few hundred amperes : such a motor would probably have a resistance of a small fraction of an ohm in the windings of the field and armature. Operating on a 500 volt circuit, if the motor was not running, the current flowing through the motors would reach several thousand amperes. This current would immediately burn up the motors ; if the circuit were not opened at once. The mechanical effect on the gearing and machine would be a shock which would be the equivalent of suddenly opening the throttle the full width on a steam locomotive at rest.

One important difference between steam locomotives and electric locomotives is, that with the steam locomotive when starting there is little or no waste of steam, as each pound of steam that goes into the cylinders gives back useful work ; for instance, a steam locomotive can stand still and pull on a train without any loss of steam other than that small amount which comes from the condensation of the steam in the cylinders. But with an electric locomotive when at a standstill, and pulling on a train, the current must be kept continuously flowing, or there will be no pull on the draw bar. However, when a steam locomotive is hauling a heavy train at a slow speed, or when accelerating a train rapidly, the steam is not used with good efficiency, so that there is not the disadvantage with electric locomotives arising from the low efficiency during the starting period that would appear at first sight. When running slowly with a heavy load, both steam and electric locomotives are generally operating with low efficiency.

An interesting similarity between the steam locomotive and the electric locomotive is, that, in both, the full amount of steam in the one and of current in the other passes through the working parts of the apparatus, but that in each only a part of the pressure is effective under the ordinary conditions during the starting period while moving. In the steam locomotive the steam is exhausted from the cylinder at a high pressure, and the efficiency of operation is therefore much reduced below what it is when all the pressure is utilized by allowing complete

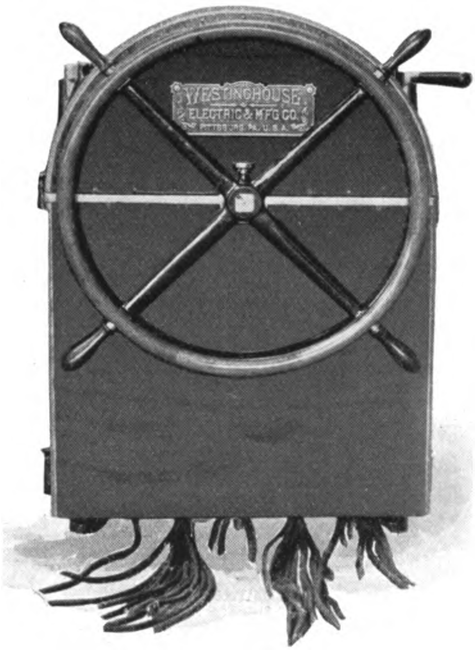
expansion. In the electric locomotive the reduction of pressure at slower speeds is effected by the resistance through which the current passes, thus leaving a reduced pressure, which produces useful work in the motors.

Figs. 53 to 56 show some of the Baldwin-Westinghouse standard controllers as applied to electric locomotives. Fig. 57 shows the standard element of resistance or diverter. The total resistance is made up of a number of these elements.

The resistance absorbs the electric energy, transforming it into heat. Why this is so is not known; at least not so well known that it can be expressed in simple terms. It is a fact, however, that when a current of electricity passes through a wire the wire resists it. The same is true if it is passed through substances of any kind and of any form. Iron gives more resistance than copper, and copper more resistance than silver. Certain alloys of iron and other materials offer more resistance than pure iron. Most alloys of copper and other metals give more resistance than copper. Any desired amount of resistance can be made from a sufficient length of any substance, but in order to reduce the bulk of the resistance as much as possible, it is customary to use a substance having a high resistance, such as iron, nickel steel, or German silver. In all forms of resistance used in electric locomotives, iron or nickel steel is used, as more resistance can be obtained at less expense than in any other way.

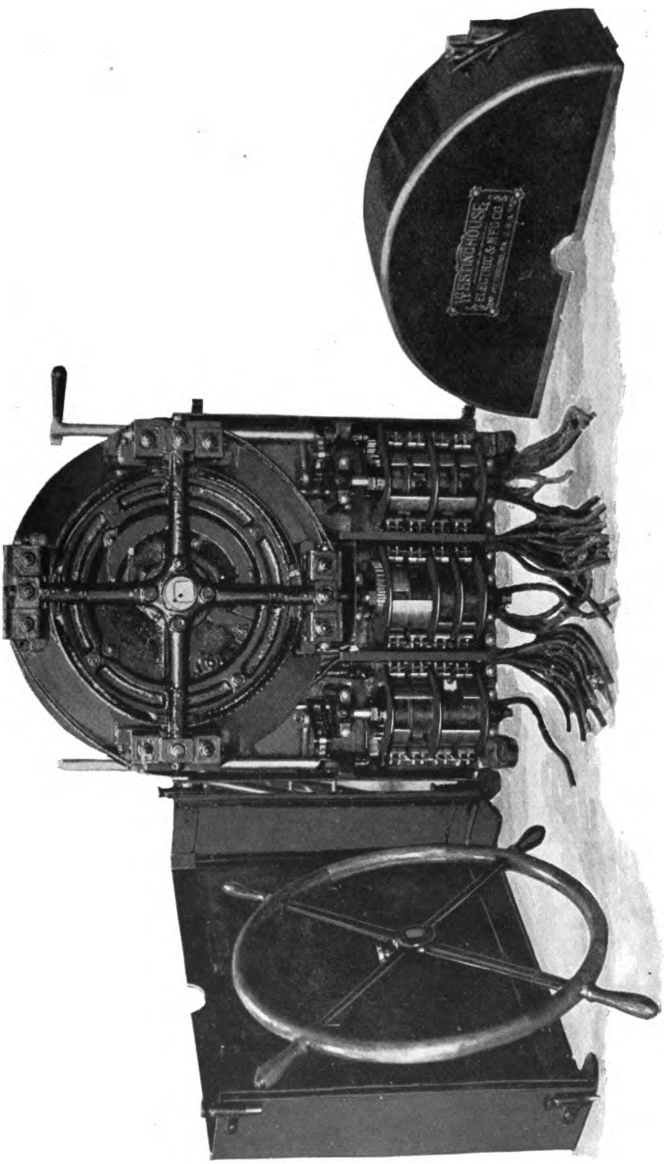
The resistances often get very hot indeed, and it is quite an important matter that they should be well ventilated; that is, a current of air should be permitted to circulate about them. To this end they are usually placed in an exposed position. They are insulated by mica or asbestos, or some other non-inflammable substance.

Fig. 53.




Controller for two 100 H.-P. Motors, End Elevation.

Fig. 54.

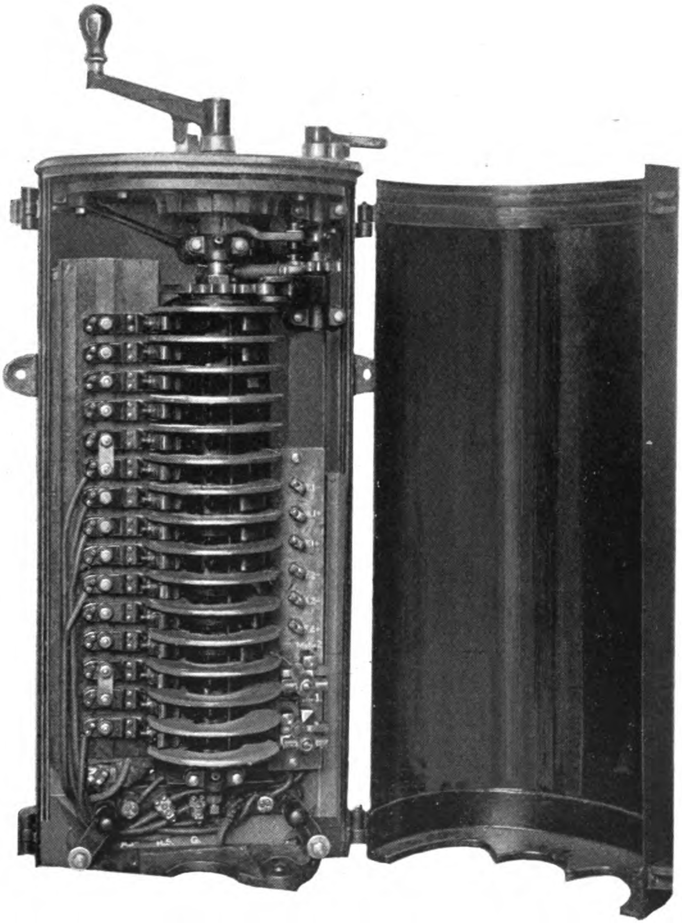



Controller for two 100 H.-P. Motors, open, showing Interior.

Fig. 55.

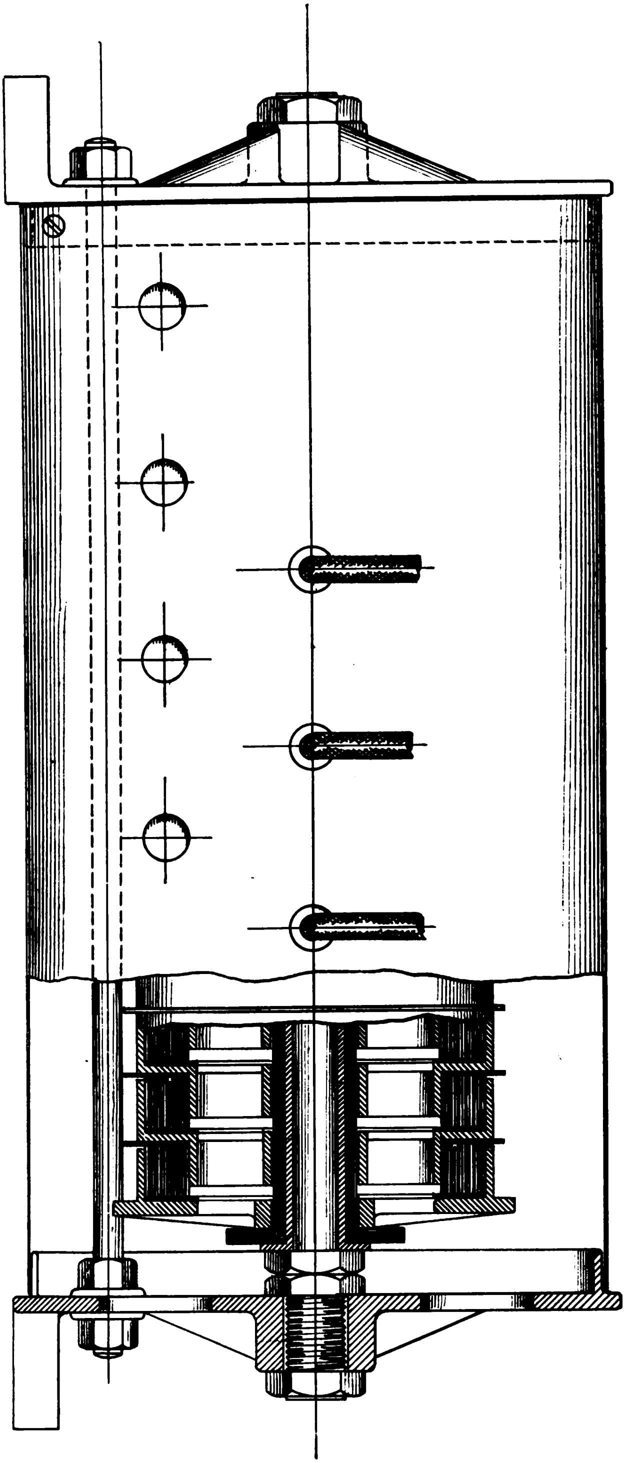
Controller for two 50 H.-P. Motors, Exterior.

Fig. 56.



Controller for two 50 H.-P. Motors, open, showing Interior.

Fig. 57.



Diverter for Electric Locomotives.

Captain

Comd'g

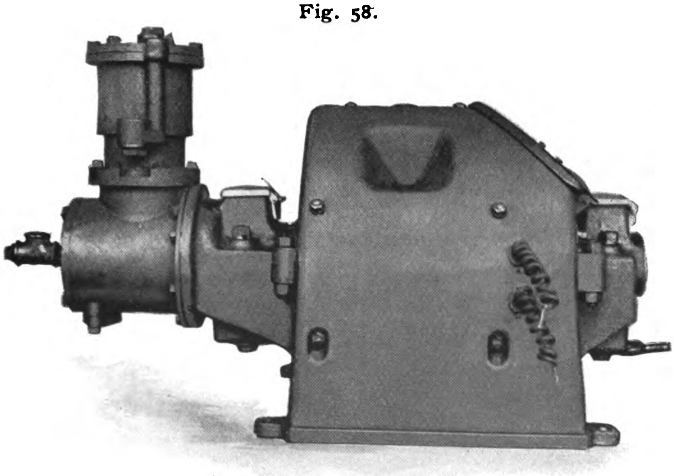


# Brake Apparatus.

On electric locomotives either the compressed air or vacuum brake may be used. The brakes are applied by means of levers and air cylinders, as usual. The engineer's valve is of the standard Westinghouse type. It has an additional connection, so that when the handle of the brake-valve is placed in the emergency position for a sudden stop, the air is admitted to a small pipe leading to the main circuit-breaker. This air opens the circuit-breaker and cuts off the electric current, so that the movement of one handle not only applies the brake, but shuts off the current, so as to give the highest possible degree of safety. In addition, there is provided a reversing switch for the motors, so that they can be made to stop the locomotive or train by backward pull.

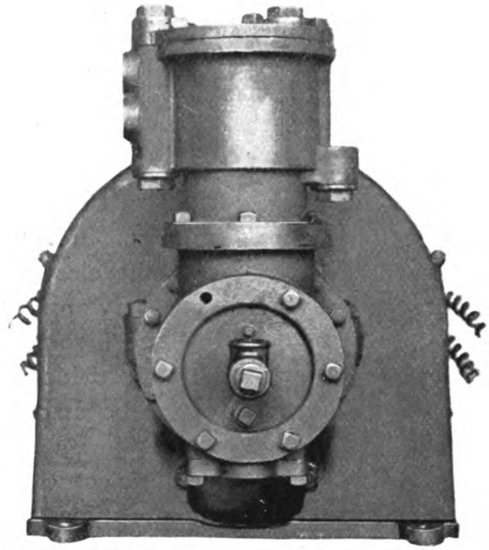
The automatic air-pump is driven by electricity; the pump is of the most improved Westinghouse type. The electric motor which drives the pump is direct-connected, and without gears. The gearless motor is used on this pump to avoid the disagreeable sounds which are found to be objectionable in geared air-pumps. Figs. 58 to 59 show the general features of the design.

**Fig. 58.**



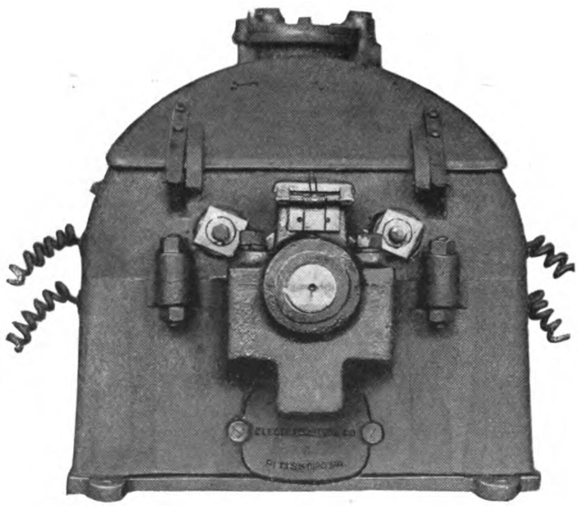
**Direct Connected Air-Pump.**

Fig. 59.



Direct Connected Air-Pump, showing Pump End.

Fig. 60.



Direct Connected Air-Pump, Motor End.

# Safe Weight for Light Rails.

It has been found by practical experience that steel rails, properly supported by cross-ties, can sustain, as a maximum, a weight per wheel of 2240 pounds for each ten pounds weight per yard of rail.

# Draw-Bar Pull.

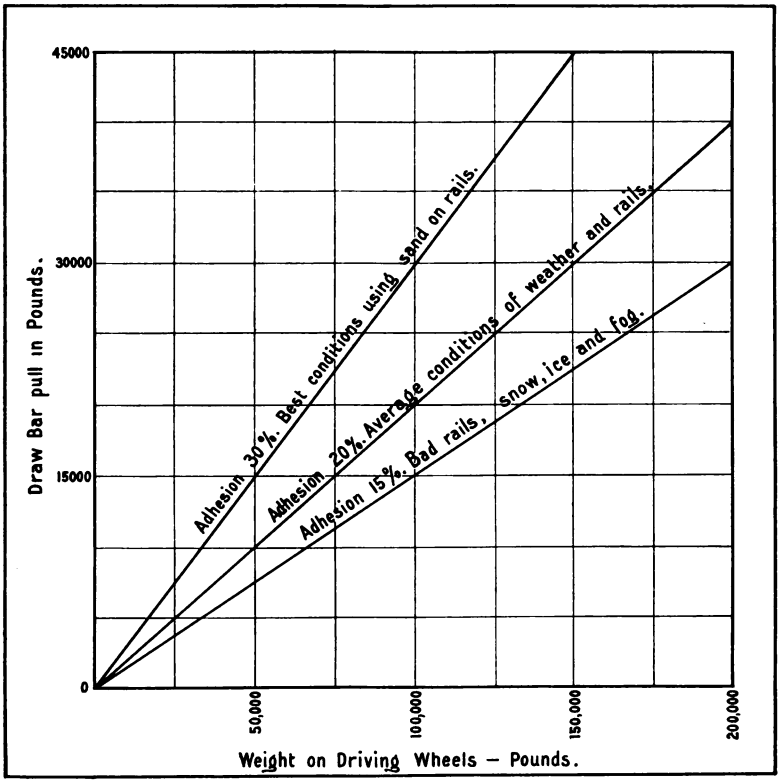
The draw-bar pull of an electric locomotive depends upon its weight on drivers, as the torque or pull of the electric motor is sufficient to slip the drivers. The total weight of the locomotive may be upon the driving wheels; carrying wheels or wheels without motors being unnecessary except in special cases.

The diagram, Fig. 61, shows the draw-bar pull with different weights on the drivers under various conditions of rail. When the weight on drivers is known, this diagram gives directly the hauling power of the locomotive, including its own weight. To determine the train load that can be hauled on any grade and under any common conditions, consult the diagrams, Figs. 62 to 67.

NOTE.—The effect of speed on the resistance of trains is small for all velocities up to sixty miles an hour. Above that point the air resistance becomes a more important factor. But the accidental increase of resistance due to the side winds in the open country, and due to bad oiling or bad track, are so much greater than the head air resistance, that when proper allowance is made for these accidental resistances, there is generally sufficient margin to cover all resistance arising from the velocity through the air up to seventy miles an hour. Above seventy miles a small allowance must be made for head air resistance.

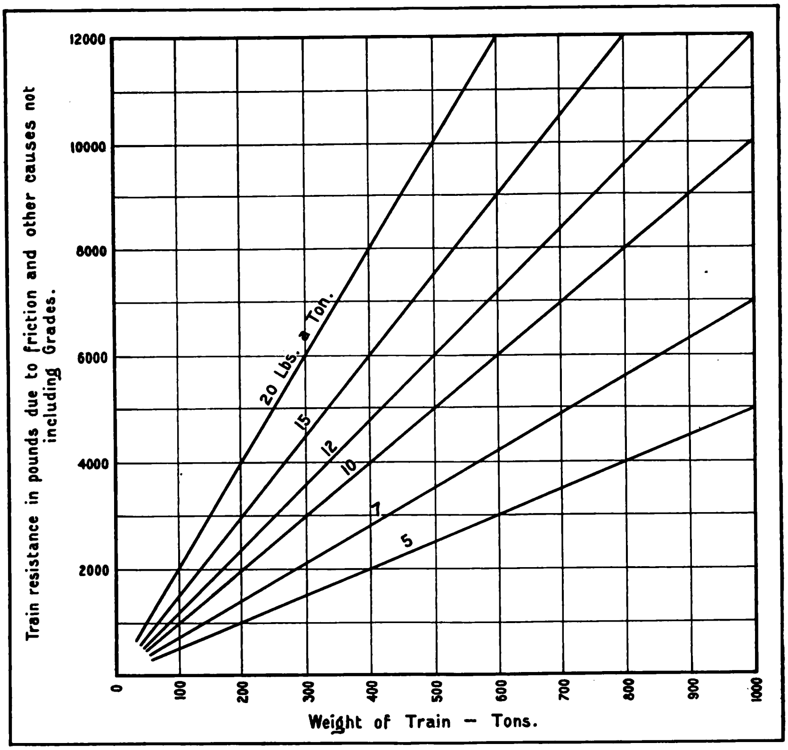
The margin of power in electric locomotives at any speed can be found from the diagrams, Figs. 36 to 50.

Fig. 61.



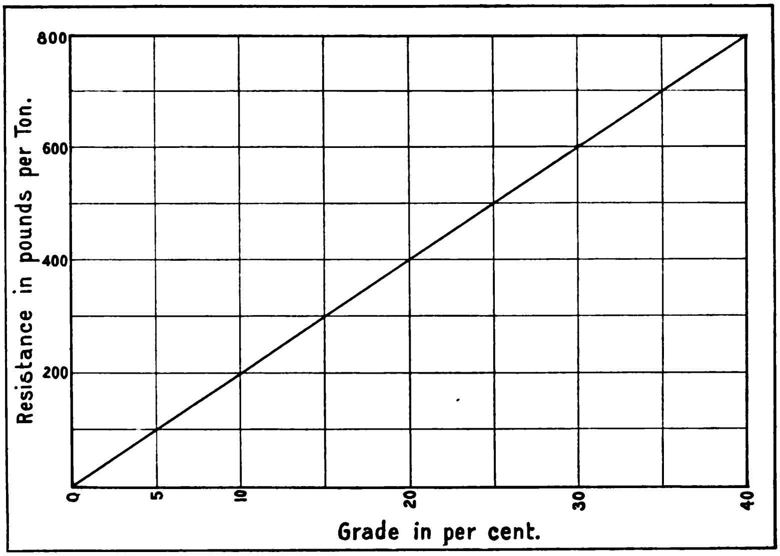

Weight on Driving-Wheels and Draw-Bar Pull.

Fig. 62.



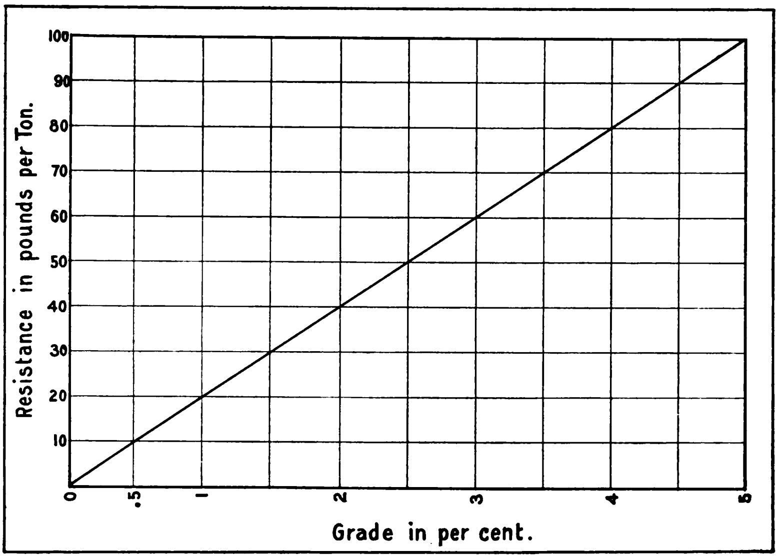

Train Resistance due to Friction.

Fig. 63.



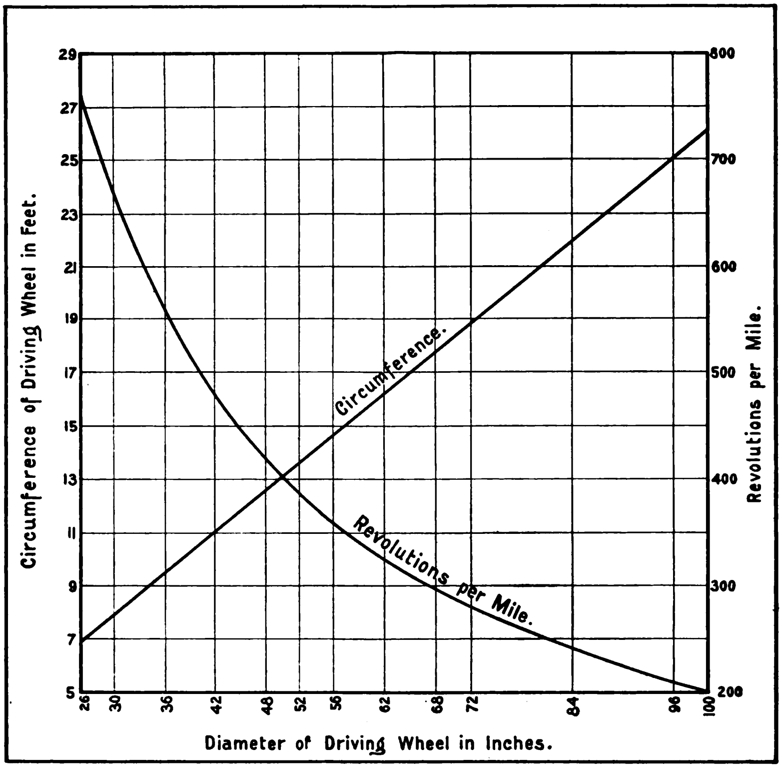

Resistance due to Grades, 0 to 40 per cent.

Fig. 64.



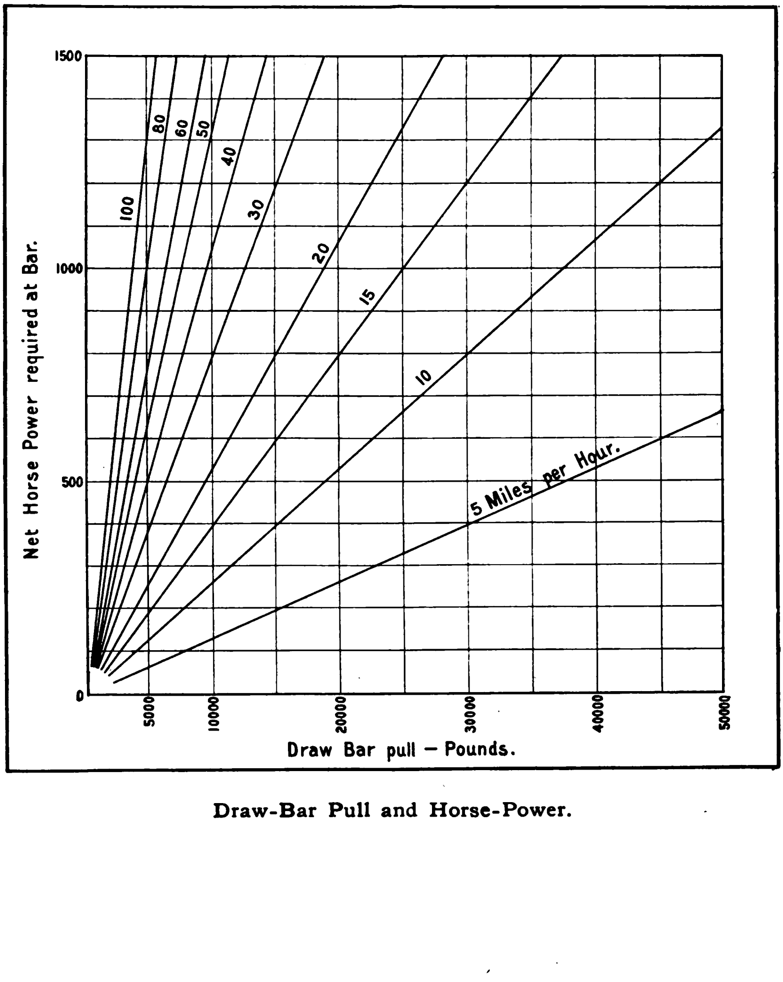

Resistance due to Grades, 0 to 5 per cent.

Fig. 65.



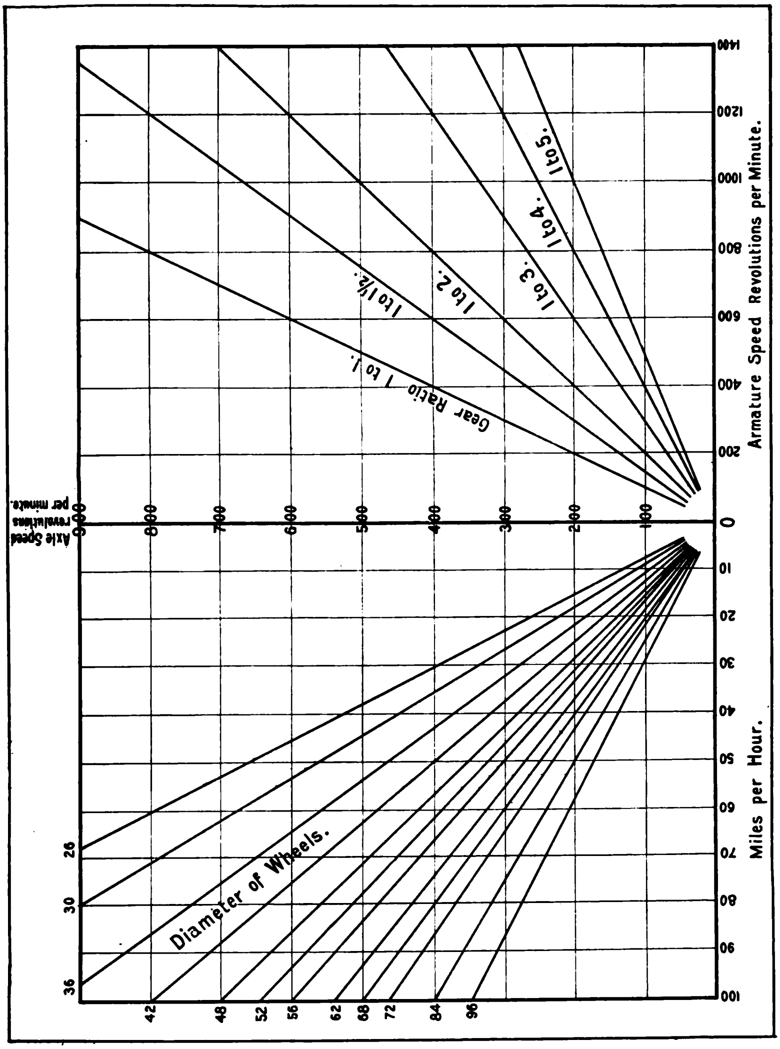

Circumference of Drivers and Revolutions per Mile.

**Fig. 66.**




**Draw-Bar Pull and Horse-Power.**

Fig. 67.




Armature Speed Gear Ratio, Axle Speed, and Miles per Hour.

# Form of Specification.

Class .................................... ) (Drawing No. ....................................

## SPECIFICATION.

No. ....................

Of an Electric Locomotive Engine, having .................................... Motors and .................... pairs of driven wheels .............................................. coupling rods, for the ........................................................................ Company.

## GENERAL DESCRIPTION.

**Design.** General design illustrated by attached photograph of engine ..........................................................................................................

**Dimensions.** Driving-wheels .................... inches diameter. Gauge ...................... feet ...................... inches. Type of motors ........................... Voltage ........................ Total wheel-base .................... feet ................ inches. Driving wheel base ...................... feet .................... inches. Total wheel-base of locomotive not to exceed ................... feet ......................... inches.

**Weight.** Weight in working order, total about .................................. pounds; on driving-wheels about .................................. pounds.

**Limits.** Of height ......................... feet ......................... inches; of width .................. feet ..................... inches.

## FRAMES.

**Frames.** Of..........................................................................................

## TRUCKS.

**Plan.** Centre-bearing swivelling,..............................wheeled truck ..............................

**Frame.** Truck frame of wrought iron, with braces of wrought iron; fitted with swinging bolster, or with fixed centre-bearing.

**Driving-Wheels.** ..........................in number; ..........................inches in diameter. Centre of..........................iron turned to.......................... inches diameter..........................................................................................

**Tires.** Of cast steel, ..........................inches thick when finished; ..........................pairs flanged, ..........................inches wide; .......................... pairs plain, ..........................inches wide.

**Axles.** Of hammered iron or steel; journals.......................... inches diameter and ..........................inches long. Driving-boxes of cast iron, with brass bearings.

**Springs.** Of crucible cast steel, tempered in oil.

**Rods.** Parallel-rods of steel or hammered iron, with solid ends and heavy brass bushings. Bushings put in by hydraulic press and well secured from turning in rod.

**Oil-Cups.** Lubrication of all bearings carefully provided for, and oil-cups attached where required. Wick or adjustable needle oil-cups on rods.

**Wrist-Pins.** Wrist-pins of steel or wrought iron.

## ACCESSORIES.

**Cab.** ..................................................

**Pilot.** Of wood braced with iron.

**Furniture.** Engine to be furnished with..................sand-boxes, stand for head-lamp, bell; also a complete set of tools, consisting of two heavy jack-screws and levers, one heavy pinch-bar with steel point and heel, complete set of wrenches to fit all nuts and bolts on engine, including two monkey-wrenches, one set of driving-box packing-tools, one machinist's hammer, one soft hammer, three cold chisels (two flat and one cape), one long-spout quart oil-can, one two-gallon oil-can, one torch, cab seats, and cab-seat cushions.

**Headlight.** ..................................................

**Brakes.** ..................................................

## FINISH.

**Finish.** ..................................................

**Painting.** Engine to be well painted and varnished.

Lettering and numbering to be as specified by purchaser.

## GENERAL FEATURES OF CONSTRUCTION.

**Gauges.** All principal parts of engine accurately fitted to gauges and templates, and thoroughly interchangeable.

**Alloy.** All wearing brasses made of phosphor bronze or ingot copper and tin, alloyed in proportion to give best mixture for wearing bearings.

**Threads.** All threads on bolts to United States standard.

## PHYSICAL TESTS OF MATERIALS.

All materials used in the construction of the locomotive shall be of the best quality of their respective kinds, carefully inspected and subjected to the following tests. Notwithstanding these tests, should any defects be developed in working, the corresponding part will be rejected.

**Bar Iron.** Bar iron should have a tensile strength of 50,000 pounds per square inch, and an elongation of twenty per cent., in section originally two inches long. Iron will not be accepted if tensile strength falls below 48,000 pounds, nor if elongation is less than fifteen per cent., nor if it shows a granular fracture.

**Steel Plates for Frames and Trucks.** Tank plates to be rolled from homogeneous steel billets, and must be of good finish, free from surface defects, such as spawling or bad buckling. The steel to be of such quality that pieces taken lengthwise of any plate selected shall show no sign of fracture when bent double cold over a mandrel, whose diameter is one and one-half times thickness of plate so tested.

**Steel for Forgings.** All blooms must be of open-hearth steel, not exceeding 0.05 in phosphorus.

Steel blooms should be of such quality that a test piece, cut from a forging four inches in diameter, hammered from the bloom and allowed to cool, should, when tested, have a tensile strength of 80,000 pounds per square inch, and an elongation of twenty per cent. in a section originally two inches long.

Blooms will not be accepted that show a tensile strength of less than 75,000 or more than 90,000 pounds per square inch, or an elongation of less than fifteen per cent.

**Spring Steel.** All spring steel must be manufactured by the crucible process, and must be free from any physical defects.

The metal desired has the following composition:

| | | |
|---|---|---|
| Carbon | | 1.00 per cent. |
| Manganese | | 0.25 " |
| Phosphorus | not over | 0.03 " |
| Silicon | " | 0.15 " |
| Sulphur | " | 0.03 " |
| Copper | " | 0.03 " |

Steel will not be accepted which shows on analysis less than 0.90 or over 1.10 per cent. of carbon, or over 0.50 per cent. of manganese, 0.05 per cent. of phosphorus, 0.25 per cent. of silicon, 0.05 of sulphur, and 0.05 of copper.

**Phosphor Bronze.** All bronze to be made from new metals, and should show the following analysis:

| | |
|---|---|
| Copper | 79.70 per cent. |
| Tin | 10.00 " |
| Lead | 9.50 " |
| Phosphorus | 0.80 " |

Bronze will be rejected, should analysis show results outside of the following limits:

| | | | | |
|---|---|---|---|---|
| Tin | below 9.00 | per cent. | or over 11.00 | per cent. |
| Lead | " 8.00 | " | " 11.00 | " |
| Phosphorus | " 0.70 | " | " 1.00 | " |

Bronze will also be rejected in case it contains 0.50 per cent. of any other substance than the four elements mentioned in this specification.

## ELECTRICAL EQUIPMENT.

**Motors.** To be of the best steel-clad consequent pole type, with ventilated armatures, forged copper, mica insulated commutators and symmetrical windings. The insulation of all of the parts to be of the best quality. The air gap to be as large as practicable, to reduce unequal wear on the bearings and to prevent the armature from striking the pole pieces when the bearings are worn. The motors to be entirely encased with the steel fields and lids, so as to prevent as much as possible the entrance of dampness

and dust. The upper field castings to have an opening with a removable cover to give access to the brushes. The lower field castings to be provided with hand-holes and air-tight covers. The brush holders to be adjustable radially to allow for wear of commutators. The armature bearings to have oil wells beneath and sponge boxes above, and to have protection flanges to prevent oil from reaching the armatures.

**Gears.** The gears and pinions to be of cast steel, or the highest grade of malleable iron, and to have wide faces to reduce the wear. The pinion on the armature shaft to have a taper fit and key, and to be held by a nut which will be made a tight fit, to prevent turning off. All gears to be surrounded by oil-tight gear casings, securely held to the motors.

**Controllers.** To be arranged for series, series multiple or multiple control, as specified, and have sufficient capacity to enable the motors to exert full power without overheating the contacts in the controller. The controller brushes to be of the best practical form, and the insulation of the best quality.

**Collecting Devices.** To be well constructed, and of the best design for the type selected by the purchaser.

**Rheostats.** To be made of iron, with mica insulation of the best form for the type selected by the purchaser, and to be mounted so as to give the best possible ventilation to reduce the heating.

**Wiring.** All wiring, where possible, to be encased in lead or iron pipes or best quality canvas or canvas and rubber hose, according to the location and exposure.

**Accessories.** All electrical details and apparatus necessary to make these locomotives complete, operative, and practical machines, are to be provided without extra charge to the purchasers.

# Data Required for a Preliminary Estimate of the Cost of Electrical Equipment.

Length of road, .......... miles.

Gauge of track (inside distance between rails), .......... feet .......... inches.

Kind of rail (T-iron or otherwise), ..........

Weight of rail per yard, .......... pounds.

Size of cross-ties, .......... inches wide, .......... inches deep.

Distance apart, .......... inches from centre to centre.

Maximum grades, .......... per .......... ; length, .......... .

Shortest curves, .......... feet radius ; length, .......... .

The maximum grade and shortest curve occurring in combination are: Grade, .......... feet per .......... ; curve, .......... feet radius ; length of curve, .......... feet.

The service required is to haul .......... cars, each weighing, with its lading, about .......... pounds, up the grade of .......... per .........., combined with curve of .......... radius.

Each car weighs, empty, about .......... pounds. The wheels are loose or fixed on axles?

Do the journals run in oil-boxes? .......... .

The train to be hauled .................... miles per hour on a level will be as follows: number of cars, .................... ; weight of each car, empty, .................... ; weight of load on each car .................... ; making total train weight of .................... .

The engine is required for .................... service. (Passenger, freight, or mixed.)

The limit of extreme width of engine must be .................... . The limit of height from top of rail must be .................... . If buffers are used, the distance apart from centre to centre will be ...................., and the height from level of rail to centre of buffer will be .................... .

The kind of couplings required, .................... . Height from rail to centre of coupling is .................... .

The turn-tables are .................... feet in diameter.

From what source is power available for driving electric generators in the central stations, waterfalls or fuel?

If waterfalls, give the minimum total power of each fall in a dry season, and the location of each fall with respect to the line of the road: ....................

If fuel, state character, quality, and approximate cost per ton (2240 pounds) delivered at central stations; also state if water can be obtained for condensing engines: ....................

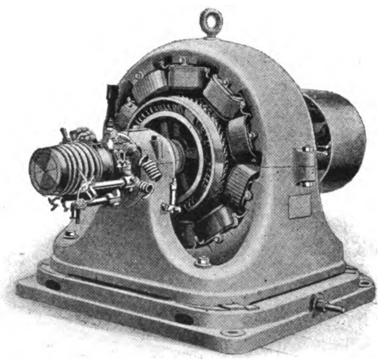
The kind of boiler feed-water is ....................

# A Simple Glossary of Terms Frequently Used in Electric Railroad Work.

**Accumulators.** A name given to storage batteries. (See *Storage Batteries.*)

**Air Gap.** The distance between the surface of the armature and the surface of the field magnets or pole pieces; sometimes called "air space."

**Alternating Current.** A reciprocating current; one which reverses continuously and regularly in direction. The induction produced by the variation of electric current permits a change of the electric pressure to a lower or higher voltage by the use of a device called the converter. (See *Converter.*) (See *Polyphase.*)



**Alternators.** A name given to dynamos which generate alternating currents.

**Ammeter.** A device or gauge for measuring the number of amperes flowing in a circuit.

**Amperage.** This is a term sometimes used to signify the amount of current; thus: when 500 amperes are flowing through a circuit, the "amperage" is said to be 500.

**Ampere.** The standard unit of electric current. It is the current that will flow through one ohm of resistance when the pressure to force the current through the resistance is one volt. The number of amperes is equal to the number of volts pressure divided by the number of ohms resistance through which the current flows.

**Armature.** That part of a dynamo which contains the wires or conductors in which the current is generated. The armatures do not always revolve; sometimes the field revolves and the armature is stationary.

**Automatic Circuit Breaker.** (See *Automatic Switch.*)

**Automatic Switch.** A switch arranged to open automatically whenever the current exceeds a given amount. This is generally done by passing the current through one or more turns of copper wire around an iron core, which makes an electro-magnet. The pull of the magnet increases as the current increases, and when the pull has reached a given amount it either opens the switch or releases a catch, which permits a spring to throw the switch open. Sometimes the magnet opens a valve which admits compressed air to a piston, which forces the switch open.

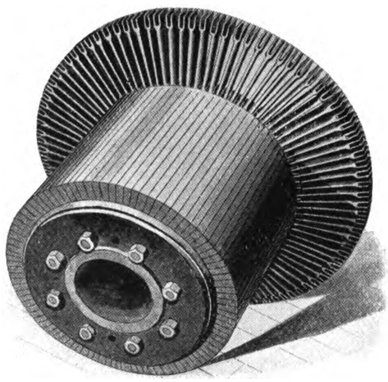
**Brake Horse-Power.** The horse-power as measured by a dynamometer placed on one of the shafts of a machine. The brake horse-power of a motor is generally measured on the armature shaft, the gearing not being included.

**Brushes.** The devices which rub or slide upon the commutator, and through which current is collected. Formerly brushes were built up of thin sheets of copper, but in modern dynamos and motors for regular work the brushes are usually made of carbon held in brass or copper holders. The carbons are held against the commutator by light springs.

**Brush Holders.** The devices by which the brushes are held in position. Commonly, brush holders are arranged so that they may be shifted slightly to prevent flashing or sparking at the commutator.

**Circuit.** The succession of conductors through which a current passes, no matter how crooked or complex.

**Commutator.** The set of contacts on the armature of a dynamo or motor through which the current passes between the brushes and the armature wiring. The contacts are usually made in the form of a drum, consisting of copper segments, separated by thin layers of mica for insulation. The commutators are not only used for collecting the currents from dynamos and distributing the currents into electric motors, but are also used to subdivide the resistance in rheostats, so that more or



less resistance can be used, according to the location of the sliding contact on the face of the commutator. Such a resistance is said to be a "commutated" resistance.

**Compound Winding.** The field magnets of motors and dynamos sometimes have two windings, through one of which passes the main current and through the other a branch of the main current. The winding through which the main current flows is known as a "series" winding, while the other is called a "shunt" winding; the two together make a compound winding.

**Conductors.** Any part of a dynamo or motor or electric line through which the electric current flows.

**Conduit System.** A system of conducting current to moving motors or trains, which consists of an excavation or trough in the earth, in which are placed conductors, on which slide or roll the collectors.

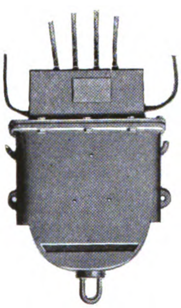
**Consequent Pole.** A magnetic pole of a motor or dynamo, around which there is generally no wires and no current passing. It is formed in consequence of its position between two poles of the same polarity.

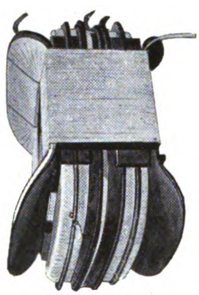
**Constant Current.** A current that is constant in quantity,—that is, one which has a constant number of amperes at all times.

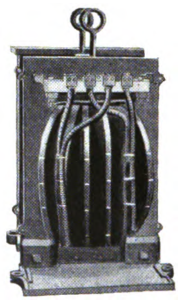
**Constant Potential.** Constant voltage or constant pressure.

**Continuous Current.** (See *Direct Current.*)

**Converter.** An apparatus used with alternating currents. It consists of three elements: a primary coil supplied with current from the source, a secondary coil for supplying the work circuit, and an iron core magnetically joining the two coils. The varying induction in the primary induces an electro-motive force in the secondary. The primary and secondary electro-motive forces are directly proportional to the number of turns on the respective coils, so that by suitable windings the pressure may be raised or lowered. The current in the two coils is inversely proportional to the respective turns. (See *Transformer.*)







**Copper Loss.** The loss of energy, which appears as heat, from resistance of the copper conductors in a dynamo or motor.

**Counter Electro-Motive Force.** Any electro-motive force or pressure that acts in an opposite direction to the direct electro-motor force and tends to reduce it. An electric motor driven by a direct electro-motive force may be considered to generate an electro-motive force contrary to the direction of the direct electro-motive force. This back pressure of the motor is called its counter electro-motor force.

**Direct Current.** A current that flows continuously in one direction, as distinguished from an alternating current.

**Diverter.** A resistance which is placed in an electric circuit, with a motor, to reduce it by increasing the resistance to its passage.

**Drum Switch.** A switch arranged on a drum, or cylinder, so that, as the drum revolves, the switch may be opened and shut. Generally the drum contains several switches. Such a switch is often used in controllers.

**Dynamometer.** *Siemens.* An instrument for measuring electric currents, consisting of a fixed and movable coil, through each of which the current is passed, and the force exerted between the two is measured by tension on a spring.

**Dynamometer.** A device for measuring the pull of an electric-motor or locomotive; also, for measuring horse-power. (See *Prony Brake.*)

**Eddy Currents.** (See *Foucault Currents.*)

**Efficiency.** In electric railroad work two kinds of efficiency are frequently referred to: the electric efficiency, which is the efficiency of the devices which conduct the electricity and, in some cases, transforms it from one pressure to another; and mechanical efficiency, which is the efficiency of the devices which transform the power of the electric current into useful mechanical work. The electrical efficiency of

a line conductor is the efficiency with which it transmits electric energy from one point to another. The electrical efficiency of the dynamo is the efficiency with which it transmits the torque or twist on the shaft into electric energy. The mechanical efficiency of the motor is the efficiency with which it transmits the electric energy into torque or twist on the shaft, thus producing useful mechanical work. These terms are loosely used at the present time, and statements of efficiency should always be accompanied by explanation as to the real meaning.

**Electrical Horse-Power.** Simply the horse-power of electric current. It is the same as mechanical horse-power, and represents a rate of work, viz.: 33,000 foot pounds per minute. It is found by multiplying the electrical pressure, or volts, by the current or amperes, and dividing by 746. The product of the volts and amperes gives the number of watts, so called. 746 watts represent a horse-power. (See *Watt.*)

**Electro-Magnet.** A magnet formed by an iron or steel core around which wires are wound and through which current passes. Its production by a current through the winding distinguishes it from a permanent magnet. The field poles of dynamos and motors are electro-magnets.

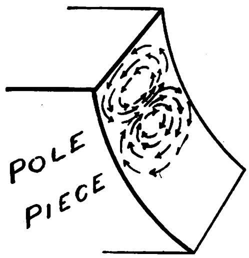
**Electro-motive Force.** The number of volts pressure in an electric circuit. Often called electric pressure. The letters *E.M.F.* are used to indicate electro-motive force or pressure.

**Energy.** A term which has many meanings, but is ordinarily understood to be the work which a body or machine is capable of performing. A mass of any kind in motion can do work when it is stopped. This capacity of a body gives rise to the term "stored energy." A horse-power is the rate of use of energy or the rate of giving up energy. One horse-power is fixed at 33,000 foot pounds per minute.

**Field.** That part of the motor or dynamo which contains the magnets, between which or around which the armature revolves. Sometimes the machines have rotary fields and stationary armatures instead of stationary fields and rotary armatures, as in the more common construction.

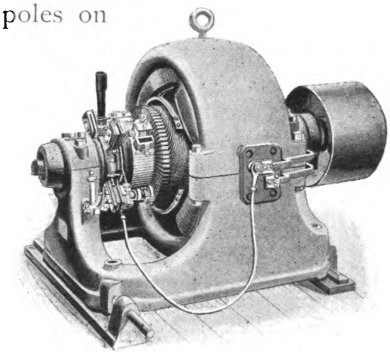
**Field Magnets.** The iron projections of the field which confront the armature surface and in which magnetism is produced by the exciting current which flows in coils around the magnet.

**Flashing.** (See *Sparking.*)




**Foucault Currents.** The local currents that are induced in the pole pieces and armatures of dynamos and motors which do no useful work. An electro-motive force is set up in the body of the armature and often in the field poles which tend to produce currents. These currents are largely prevented by the lamination of the iron, which places a large resistance in the path of the current. The effect of these currents is to heat the armatures and pole pieces, and the heat so generated represents a loss of energy. It is the aim of designers to reduce these currents to a minimum; hence the use of laminated poles and laminated armatures. (See *Eddy Currents.*)

**Frequency.** The number of alternations per minute of alternating currents found by multiplying the revolutions per minute by the number of poles on the dynamo or alternator.



**Fuse Block.** A fuse is a strip of metal of low melting point, which melts and opens the circuit when the current exceeds an amount which the fuse is designed to carry without overheating.

**Generators.** The dynamos in the central station which generate electric current.

**Horse-Power.** The standard rate of work. It is 33,000 foot pounds per minute. Any machine doing in one minute an amount of work equal to 33,000 foot pounds is performing work at the rate of one standard horse-power. The amount of work performed by any machine is the product of the force exerted by the machine, and the distance through which the force goes. Thus, if a machine pushes with a force of 1000 pounds over a distance of 33 feet in a minute, the machine is doing work at the rate of one horse-power.

The accepted abbreviation of the term horse-power is the symbol *H.P.*

**Hysteresis.** The loss and resulting heating of an iron core in which there is alternating magnetism, as in the cores of armatures. This is a kind of magnetic friction between the particles due to change of position when the magnetism is reversed.

**Induced Currents.** (See *Eddy Currents.*) (See *Foucault Currents.*)

**Induction.** Effects produced in one medium by electric or magnetic action in another medium. An electric current induces magnetism in the surrounding medium to a small extent if the medium be air, and to a great extent if the medium be iron. A conductor or coil has a current induced in it if it be moved near a magnet or if the magnet vary in strength. Electric current passing through one wire induces a current in other wires which are approximately parallel and adjacent to it. A magnet induces magnetism in iron or steel near which it is placed. These properties are called electric and magnetic induction.

**Insulation.** A non-conducting substance, one through which electricity will not pass. Copper conductors are surrounded by rubber, mica, resin, varnish, or other substance for preventing passage of current from the conductor. Air is an excellent insulation.

**Iron Losses.** The losses which arise in dynamos and motors from the eddy, induced, or foucault currents which are induced in the iron during the operation of the machine, and from hysteresis. These losses, with the exception of hysteresis losses, are reduced by using laminated armatures and laminated pole pieces.

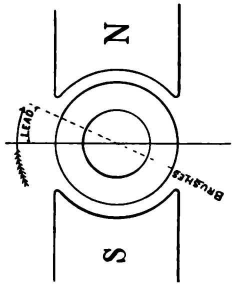
**Kilowatt.** 1000 watts, that is: 10,000 watts is 10 kilowatts. The letters K. W. are used as an abbreviation for kilowatts.

**Lag.** The retardation of one alternating current behind an electro-motive force or another current; the maximum and zero values of one occur slightly later than those of the other. The term is also used to define the lagging of magnetic intensity behind the variations of the current producing it.

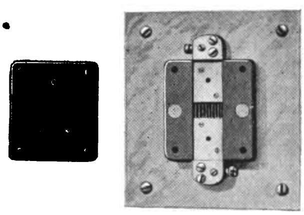
**Laminated Armatures.** Armatures formed of thin sheets of wrought iron placed side by side to form a drum. All armatures for railway motors and generators are laminated. The object of the lamination is to reduce the iron losses arising from induced, eddy, or foucault currents, which are generated in the iron of the armature. The slight oxidation of the surface of the thin iron plates reduces these currents by offering resistance to their flow. (See *Eddy Currents.*) (See *Foucault Currents.*) (See *Iron Losses.*)

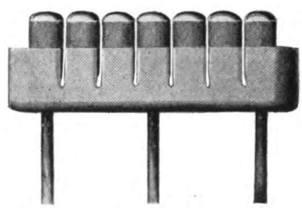
**Laminated Poles.** Poles formed of thin sheets of wrought iron, and attached to the field magnets. The object in using laminated poles is to reduce the iron losses in the machine; that is, to reduce the losses from local eddy currents in the face of the poles. The slight oxidation on the surface of the thin plates offers resistance to the passage of local currents and reduces them, and thus reduces the loss from those currents. (See *Eddy Currents.*) (See *Foucault Currents.*)

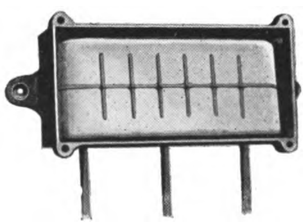
**Lead of Brushes.** The number of degrees which the brushes are placed ahead of the centre line between the pole pieces on any dynamo or motor. The real poles of a dynamo or motor, when the machine is running, are not located in front of the magnetic poles or the field, but somewhat in advance in the direction of rotation of the machine. The brushes are placed about as many degrees ahead as these resultant poles are ahead of the pole pieces. This angular advance is called the lead.




**Lightning Arresters.** Devices that are placed in electric circuits to prevent damage due to lightning. They are generally so arranged as to permit the discharge of the currents of electricity from the circuits to the earth, when the line is struck by or subjected to a discharge of electricity from the sky or the earth.







**Magnetic Blowout.** A magnet provided near a switch or point where an electric circuit is broken to deflect and dissipate the electric arc which forms when an electric

circuit is broken. It is based on that peculiar property of electric arcs which permits them to be distorted, deflected, drawn aside, or dissipated by an adjacent electric magnet. Magnetic blowouts are provided in many controllers and in many large switches.

**Magnetic Density.** (See *Magnetic Lines.*)

**Magnetic Intensity.** (See *Magnetic Density.*)

**Magnetic Leakage.** The passage of magnetism through side paths where it is not useful, such as the passage of magnetism directly between the positive and negative poles of a dynamo through the intervening space without passing through the armature.

**Magnetic Lines.** A term used in defining magnetic intensity or power. The number of lines per square inch or square centimeter measures the magnetic density or power.

**Magnetic Saturation.** (See *Magnetic Permeability.*)

**Multiphase.** (See *Polyphase.*)

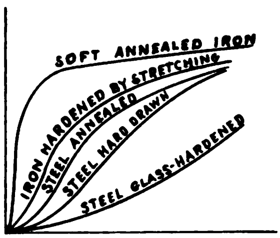
**Multiple.** A term used to describe the manner of connecting two or more motors, dynamos, or electrical devices. When the current divides and passes part through each motor or device, the motors or devices are said to be "in multiple" or "in parallel."

**Ohm.** The standard of electrical resistance. It is the resistance through which a pressure of one volt can push one ampere of current. The number of ohms resistance can always be found by dividing the number of volts pressure by the number of amperes of current flowing.

**Parallel.** (See *Multiple.*)

**Permanent Magnetism.** The magnetism which remains in an electro-magnet after the electricity is shut off. The magnetism of a horse-shoe magnet, of simple form, without wires, such as is commonly used, is permanent magnetism. The magnetism of the natural loadstone is permanent magnetism, as distinguished from the non-permanent magnetism of the electro-magnet, which is produced by the current passing through the wires, and exists only while the current is passing.

**Permeability.** The capacity of metals for magnetism. Magnetic permeability is a term used to describe the capacity of different metals for magnetization. It is found that iron or steel, for instance, receive magnetism freely up to a certain point, and thereafter an increase in the current does not give a corresponding increase in the magnetic intensity. The curve shows the increase in the power of an iron or steel magnet as the current is increased. At the point where the curves turn to the right and become nearly horizontal, the magnets are said to become saturated, and thereafter the magnetic power is not increased so rapidly.




**Permeance.** (See *Permeability.*)

**Polarity.** A magnet has two poles, called North and South. The polarity of a magnet is known as North and South polarity.

**Pole Pieces.** The field magnets. The projections on the fields which conform to the shape of the armature. Sometimes called poles. Usually made laminated on high efficiency machines. The laminations consist of thin sheets of wrought iron or steel placed side by side and riveted together and cast into the magnets of the fields.

**Poles.** (See *Pole Pieces.*)

**Polyphase.** Many phases. Alternating currents differ in phase when their maxima do not occur at the same time. Two currents sustain the two-phase relation when one has its maximum when the other has its zero value; these currents are said to be 90 degrees, or quarter-phase, apart. Three currents sustain the three-phase relation when the same interval of time occurs between the maximum value of any current and the maximum value of the current next succeeding.

**Potential.** (See *Voltage.*) (See *Electric Pressure.*)

**Prony Brake.** A device for measuring the work done by a machine. Its simplest form is a friction band passed around a pulley and clamped thereon so as to cause friction. The friction is increased by tightening the band, and the resistance of the band to motion is measured. The product of this resistance into the distance travelled by the surface of the pulley gives the foot pounds of work done per minute; and by dividing this by 33,000, the horse-power is found.

**Reaction.** The action of the field magnets, the pole pieces on armature and *vice versa.* It is the effect of the magnetism of the one on the other. This term has other meanings, which are not so frequently used in railroad work.

**Residual Magnetism.** (See *Permanent Magnetism.*)

**Resistance.** An obstruction placed in the path of electric current to increase the resistance to its passage. All material present greater or less resistance to the flow of current. Materials having the lowest resistances are called conductors, such as metals, of which copper and silver have the lowest resistance. In parts of the circuit where resistance is objectionable, such as in the line and in the armature and field coils, copper is used, and when it is desired to reduce or regulate the current by increasing the resistance, resistances, usually of iron, are placed in the

circuit. (See *Diverter.*) (See *Rheostat.*) When current passes through resistance it is reduced, and the conductors through which current passes are heated in proportion to the amount of their resistance. This may be waste, as in the drop in overhead conductors and in the armature of a machine, or it may be useful, as in the heaters of electric cars. An electric car-heater is simply a form of resistance which becomes hot by reason of the change of the energy of electric current into heat.

**Rheostat.** A resistance device which, when inserted into an electric current, increases the resistance to the passage of electric current. (See *Diverter.*) (See *Resistance.*)

**Salient Pole.** The pole of a motor field-magnet or dynamo field-magnet, around which wire is wound and through which current passes. So called in consequent pole-motors to distinguish it from the consequent pole.

**Series.** A term used to describe the manner of connecting two or more motors, dynamos, or electrical devices. When the current passes through one device or motor and thereafter passes through other devices or motors, the devices or motors are said to be "in series."

**Series Coil.** A series coil is an electric circuit through which all the current passes which is flowing through the circuit. It is distinguished by this fact from the "shunt coil," through which only a part of the current passes.

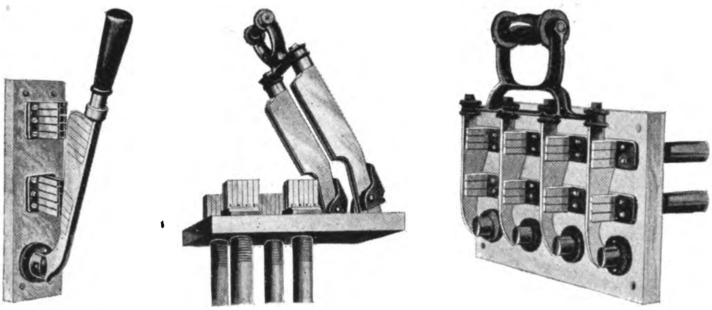
**Shunt Coil.** The coil which is inserted in an electric circuit and forms a branch through which part of the current passes. The shunt field of a machine consists of the coils which are connected directly between the brushes of the machine. The principal part of the current flows through the main branch, and a small part flows through the shunt.

**Sparking.** The flashing of electricity which occurs at the commutator when the motor or dynamo is badly designed, or when the commutator or brushes are in bad order, or the contact is not perfect, or when the motor or dynamo is overworked.

**Step-down Transformer.** The transformer used with alternating current to decrease the electric pressure.

**Step-up Transformer.** A transformer used with alternating currents, to increase the electric pressure.

**Storage Battery.** A device which stores the energy from electric current in such a way that it can be again given off as electric current. In the common forms of storage batteries, the electric current produces a chemical change in the constituents of the battery. After the change is complete, the current that is given off will be generated by a reversion to the original condition of the chemical constituents. It is not a storage of electricity, but a change of energy, from an electrical form to what may be expressed as a "chemical form," in such a way that a reverse action may take place when the terminals of the battery are connected.



**Switch.** A device for connecting two electric currents, which may be opened and shut at will, to open or close the circuit.

**Synchronism.** In alternating currents, the harmonious action between a motor and a dynamo which generates the current. In alternating currents, two machines are in synchronism when the two machines give the same number of alternations. If the machines have the same number of poles, they run at equal speed.

**Synchronous.** (See *Synchronism.*)

**Third Rail System.** A system of conducting current to moving motors or trains, consisting of an additional rail either of iron, steel or copper, laid in the track at about the same height as the main rail of the track, on which rolls or slides the collector.

**Torque.** The tendency of a shaft to turn; the twist or force which is applied to turn the shaft. It is measured in foot pounds, thus: A shaft which is turned with sufficient power to produce a pull of five pounds on the periphery of a wheel of two feet radius is said to have a torque of ten foot pounds,—that is, it will pull with a force of ten pounds at one foot radius. Sometimes torque is given in pounds. In such cases, it is understood that it is a pull at one foot radius. The proper measure of torque is in foot pounds.

**Transformer.** (See *Step-up* and *Step-down*, etc.)

**Tri-Phase.** (See *Polyphase.*)

**Two-Phase.** (See *Polyphase.*)

**Ventilated Armatures.** An armature which has slots, channels, or perforations through which air can pass to reduce heating.

**Volt.** The standard measure of electrical pressure. It is the pressure required to push one ampere of current through one ohm of resistance. The number of volts pressure required to push any given number of amperes through any given number of ohms resistance can always be found by multiplying the number of amperes by the number of ohms resistance.

**Voltage.** This is a term that has become common as a substitute for electric pressure. It means the number of volts pressure in a circuit. Where the pressure is 500 volts, the voltage is said to be 500.

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**Voltmeter.** A device or gauge for measuring or indicating the electric pressure in a circuit.

**Watt.** The rate of performance of work. It is used only in electricity, and represents $\frac{1}{746}$ part of a horse-power, or 44.23 foot pounds per minute. The number of watts which can be performed by electric current is represented by the product of the volts and amperes. This product, divided by 746, gives the horse-power.